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A SURVEY OF MAJOR EAST COAST SNOWSTORMS, 1960-1983. PART II: CASE STUDIES OF EIGHTEEN STORMS

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MARCH 1985

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A SURVEY OF MAJOR EAST COAST SNOWSTORMS, 1960-1983. PART II:

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ABSTRACT

Snowfall, surface and upper air charts, and available satellite images are presented for eighteen major East Coast snowstorms that occurred between 1960 and 1983. The charts and descriptions of key fields are provided so that students, weather forecasters, and researchers alike can visualize how a large sample of major winter cyclones form and intensify. Although there are noted similarities in certain aspects of the surface and upper-tropospheric development of the storms, significant case-to-case variability precludes the ability to effectively composite these weather systems.

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TABLE OF CONTENTS

	<u>Page</u>
1. Introduction	1
2. Individual Cases	7
a. 2-5 March 1960	7
b. 10-13 December 1960	17
c. 19-20 January 1961	27
d. 3-4 February 1961	37
e. 5-7 March 1962	47
f. 11-13 January 1964	57
g. 29-31 January 1966	67
h. 23-25 December 1966	77
i. 6-7 February 1967	87
j. 9-10 February 1969	97
k. 23-28 February 1969	107
l. 25-28 December 1969	121
m. 18-20 February 1972	133
n. 19-20 January 1978	143
o. 6-7 February 1978	155
p. 18-19 February 1979	169
q. 5-7 April 1982	183
r. 10-12 February 1983	195
3. Discussion	209
4. References	213

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1. Introduction

In this paper, snowfall charts, surface and upper air maps, and available satellite images are presented for eighteen major East Coast winter storms dating from 1960 to 1983. The storms were selected because (1) they produced significant snow accumulations in at least one major urban center that spans the corridor between Washington, D.C. and Boston, Ma., and (2) they also produced a widespread region of heavy snow accumulations. The study was undertaken to determine whether there are dynamical signatures at the surface and aloft that characterize the pre-cyclogenetic and cyclogenetic environments of intense East Coast snowstorms. The purpose of the study is to gain a perspective on how these important weather systems organize and how they evolve when heavy snow is falling in the northeastern United States urban corridor.

The surface and upper-level patterns of selected wind pressure and temperature fields are summarized for the eighteen cases (Kocin and Uccellini, 1984; hereafter referred to as Part 1), where characteristic signatures common to these storms are identified and highlighted. Miller's (1946) classification is used to categorize the storm's sea-level development into two "types." In approximately half of the cases examined, a secondary low pressure center developed along the East Coast (type "B"). In many cases where a distinct secondary low did not develop (type "A"), there still appeared to be some sort of surface redevelopment as the surface low appeared to "jump" northeastward along the Atlantic coast, typically along a coastal front. All storm events exhibited a 24 to 48 h period of deepening with at least a 12 h period of rapid deepening (greater

1

than -3 mb (3 h)^{-1}) in nearly every case. Rapid development occurred primarily along and off the Atlantic coast, as heavy snow was falling in coastal sections. Coastal frontogenesis and the damming of cold air to the lee of the Appalachian Mountains were observed in many, but not all cases. The forward motion of the surface low pressure centers not only varied from one case to another, but also varied during the course of the individual storms as several low pressure systems appeared to "stall" off the New Jersey to New England coasts during periods of rapid intensification.

At middle and upper levels, many of the trough systems that spawned these storms shared such features as diffluence downwind of the trough axis, a negative tilt of the trough axis from northwest to southeast, and an increase of the geopotential gradients at the base of the trough during cyclogenesis. In addition, confluence across the northeastern United States and southeastern Canada prior to East Coast cyclogenesis appeared to influence the evolution of cold surface anticyclones that provide the thermal support for snowfall in many of the cases. An example was presented in Part 1 to demonstrate how the configuration of a confluent jet streak entrance region over the northeastern United States and a diffluent jet streak exit region downwind of a trough nearing the East Coast can give rise to conditions conducive for snowfall along the East Coast. Despite the presence of these common features, the evolution of the upper-level trough systems differed markedly from case to case, especially in terms of the degree and timing of the amplification of the trough systems, and in the evolution and configuration of jet streak systems associated with the troughs.

The large degree of case to case variability points to the inability to properly composite the pre-cyclogenetic and cyclogenetic environments, as documented by Brandes and Spar (1971). To account for the case by case variations inherent in each storm, individual examinations of the eighteen storms are presented in this paper to highlight the variety of surface and upper-level processes that distinguish each case. The map presentations and summaries of selected fields are presented in a manner that will provide a comprehensive multi-level overview for each case prior to and during cyclogenesis along the East Coast. It is hoped that students, weather forecasters and researchers alike (especially those participating in the Genesis of Atlantic Lows Experiment--GALE) will find these descriptions useful to visualize how the storm systems form and intensify. The large selection of cases should serve as a basis for theoretical, modeling, and observational studies that are required to unravel the non-linear scale-interactive processes that spawn these storms.

Each case includes a total snowfall chart, six-paneled, twelve-hourly sequences of surface maps, 850 mb charts, 500 mb height analyses with upper-level jet axes superimposed, and infrared satellite image sequences for the five most recent cases. The case study begins with a brief summary of the storm's major effects on the East Coast. The snowfall chart was constructed from daily snowfall measurements included in issues of Climatological Data. Accumulations in excess of 10 inches (25 cm) are shaded and amounts for selected locations are noted.

The six-paneled surface charts include fronts, high and low pressure centers, isobars, and precipitation (moderate to heavy precipitation is shaded darker). The sequence of maps was chosen so the top right panel

captured the position of the surface low along the East Coast at a time when many of the storms were entering a rapid deepening stage of their development. The summary of surface characteristics includes a classification according to Miller's (1946) descriptions of surface development, cyclone track, intensification duration and magnitudes, influences of cold air damming to the lee of the Appalachians, coastal frontogenesis, and characteristics of cold Canadian anticyclones to the north of the developing cyclone.

The evolution of the lower troposphere is described through the use of 850 mb analyses. The 850 mb charts include the geopotential contours, isotherms, values of maximum 12 h geopotential height falls, and selected wind reports to highlight 850 mb low movement and intensity, the evolution of the lower-tropospheric baroclinic zone, and the development of low-level jet streaks.

The upper-tropospheric characteristics are highlighted by a six-paneled map sequence which includes 500 mb geopotential height contours, axes of jet streaks, and isotachs of maximum winds derived from 500 mb, 300 mb (250 mb for the April 1982 and February 1983 cases), or 200 mb NMC analyses. The jet analyses may not necessarily represent the jet cores, which could lie between the standard pressure levels, but should present a consistent and representative view of multiple-level jet structure. These fields are examined to address how upper-level troughs, ridges, and jet streaks evolved in space and time and how these features appear to influence the surface cyclogenesis and associated precipitation. A general overview of the large-scale circulation patterns across the United States and Canada prior to cyclogenesis is presented to infer

whether the atmosphere has recognizable patterns that precede or accompany the major snow events on the East Coast. Various aspects of the trough systems and their flanking ridges, most notably in terms of amplitude, wavelength, tilt, and the development of a closed 500 mb center, are highlighted and related to the surface cyclogenesis and development of precipitation. Changes in magnitudes of upper-level wind maxima and their locations are also discussed. Such aspects as the shortening wavelength of the trough/ridge systems and the increasing magnitudes of jet streaks, that have been discussed by Palmen and Newton (1969) and noted recently by Mullen (1983) and Uccellini et al. (1984) as being associated with non-linear processes influential in the development of cyclones, are also discussed. Associations between diffluent flow and negatively tilted troughs with rapidly deepening cyclones are discussed since these factors point to the importance of along-stream variations in the upper-level height (mass) and wind fields in the overall development of the storm systems. The discussions of upper-level features also include mention of the trough and confluent zone over southeastern Canada and the northeastern United States, and associated jet streaks.

Finally, twelve hourly GOES-East infrared imagery corresponding closely to the times of the surface and upper air analyses are also presented for the January 1978, February 1978, February 1979, April 1982, and February 1983 cases to depict the evolution of cloud systems during cyclogenesis. A brief summary of the paper is presented in Section 3.

2. Individual Cases

2-5 March 1960

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2a. 2-5 MARCH 1960

o General Remarks

- This storm was especially fierce in eastern New England. Severe blizzard conditions in eastern Massachusetts occurred with up to 30 in (76 cm) snow amounts.

Near-hurricane force winds buffeted the New England coast.

o Regions with snow accumulations exceeding 10 in (25 cm)

- eastern West Virginia, northern and western Virginia, much of Pennsylvania, parts of Maryland and Delaware, southeastern and western New York, Connecticut, Rhode Island, Massachusetts, southern Vermont, New Hampshire, and Maine

o Regions with snow accumulations exceeding 20 in (51 cm)

- eastern Massachusetts, Rhode Island
- scattered areas of northern New Jersey, southeastern New York, Connecticut, and New Hampshire

o Urban center snowfall amounts:

Washington, D.C.-National Airport	7.9" (20 cm)
Baltimore, Md.	10.4" (26 cm)
Philadelphia, Pa.	8.4" (21 cm)
New York, N.Y.-La Guardia Airport	15.5" (39 cm)
Boston, Ma.	19.8" (50 cm)

o Other selected snowfall amounts:

Nantucket, Ma.	31.3" (79 cm)
Blue Hill Observatory, Milton, Ma.	30.3" (77 cm)
Worcester, Ma.	22.1" (56 cm)
Scranton, Pa.	18.0" (46 cm)
Providence, R.I.	17.7" (45 cm)
Roanoke, Va.	17.4" (44 cm)
Allentown, Pa.	14.4" (37 cm)
Hartford, Ct.	13.0" (33 cm)
Pittsburgh, Pa.	12.8" (33 cm)

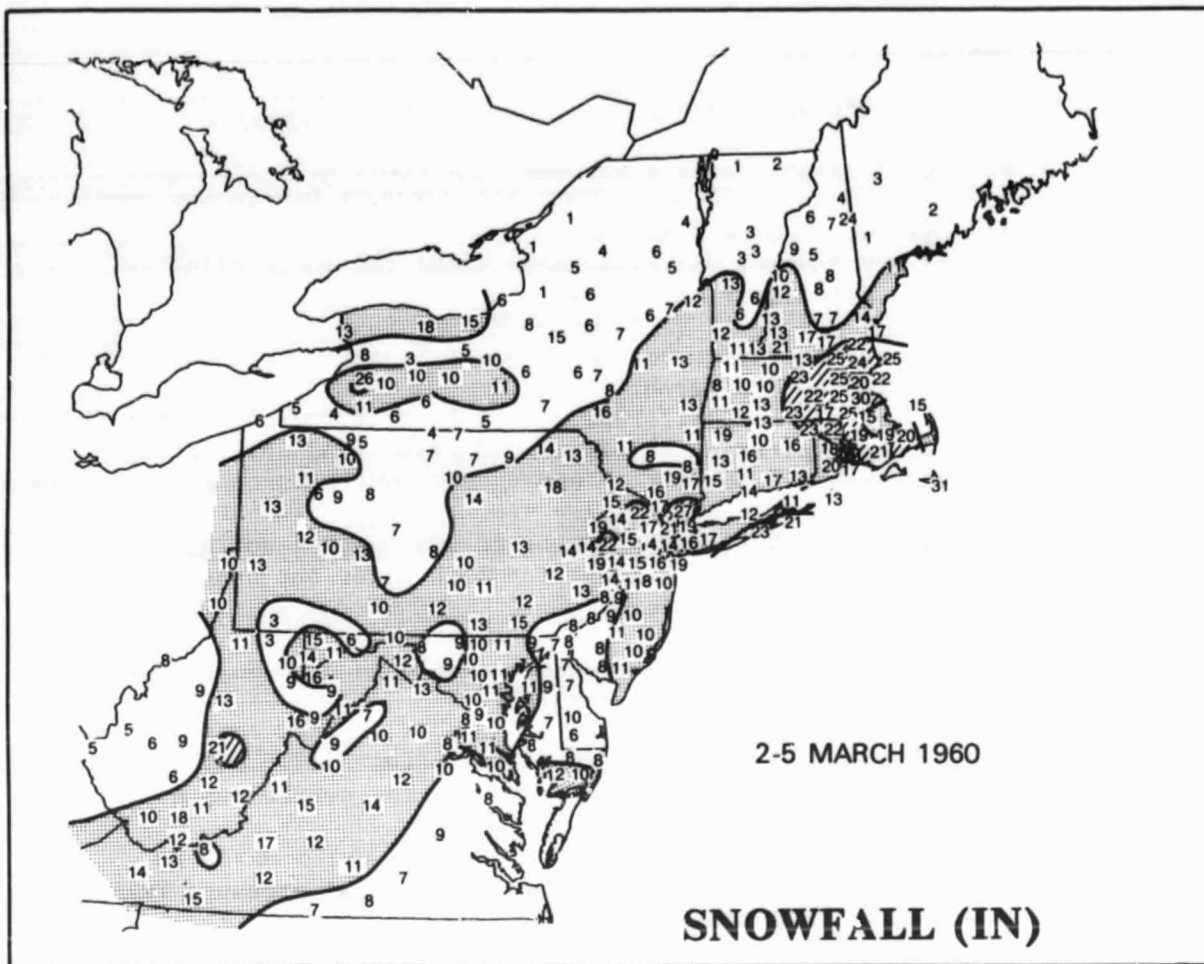


Fig. 1. Total snow accumulations for 2 to 5 March 1960 (in). Snowfall measurements are taken from issues of Climatological Data. Shading represents accumulations of 10 to 20 in (25 to 51 cm). Diagonal shading represents accumulations of 20 to 30 in (51 to 76 cm). Hatched shading represents accumulations exceeding 30 in (76 cm).

Surface characteristics

- o Type "B" (Miller, 1946)
- o A large cold anticyclone preceded the storm with its ridge axis extending from the Great Lakes states to the Middle and South Atlantic Coast on 2-3 March.
 - Cold air damming was pronounced along the South Atlantic Coast, especially on 2 March.
- o The primary low pressure center moved from the Gulf Coast to the Ohio Valley on 2-3 March.
 - This low was a significant system by itself with moderate to heavy precipitation across the Tennessee and Ohio Valley. The low deepened 8 mb in 12 h ending 0000 GMT 3 March prior to the development of the secondary low. It then deepened erratically, but slowly, prior to dissipation during 3 March. The primary low was evident for 15 h after the onset of secondary cyclogenesis.
- o The secondary low pressure center developed over South Carolina beginning around 0000 GMT 3 March.
 - The secondary low developed along a pronounced coastal front off the Southeast Coast and formed between 1200 GMT 2 March and 0000 GMT 3 March as cold air damming penetrated as far south as northern Florida.
 - The low center deepened 45 mb from 0000 GMT 3 March to 1200 GMT 4 March, at which time the central pressure fell to 960 mb off New England.
 - The movement of the storm center was quite rapid from Carolinas to off the New Jersey coast, but its subsequent movement off the New England coast was relatively slow as the lowest pressure was reached. The slow movement off the New England coast, combined with strong easterly flow, prolonged snowfall and enhanced accumulations across southeastern New England.

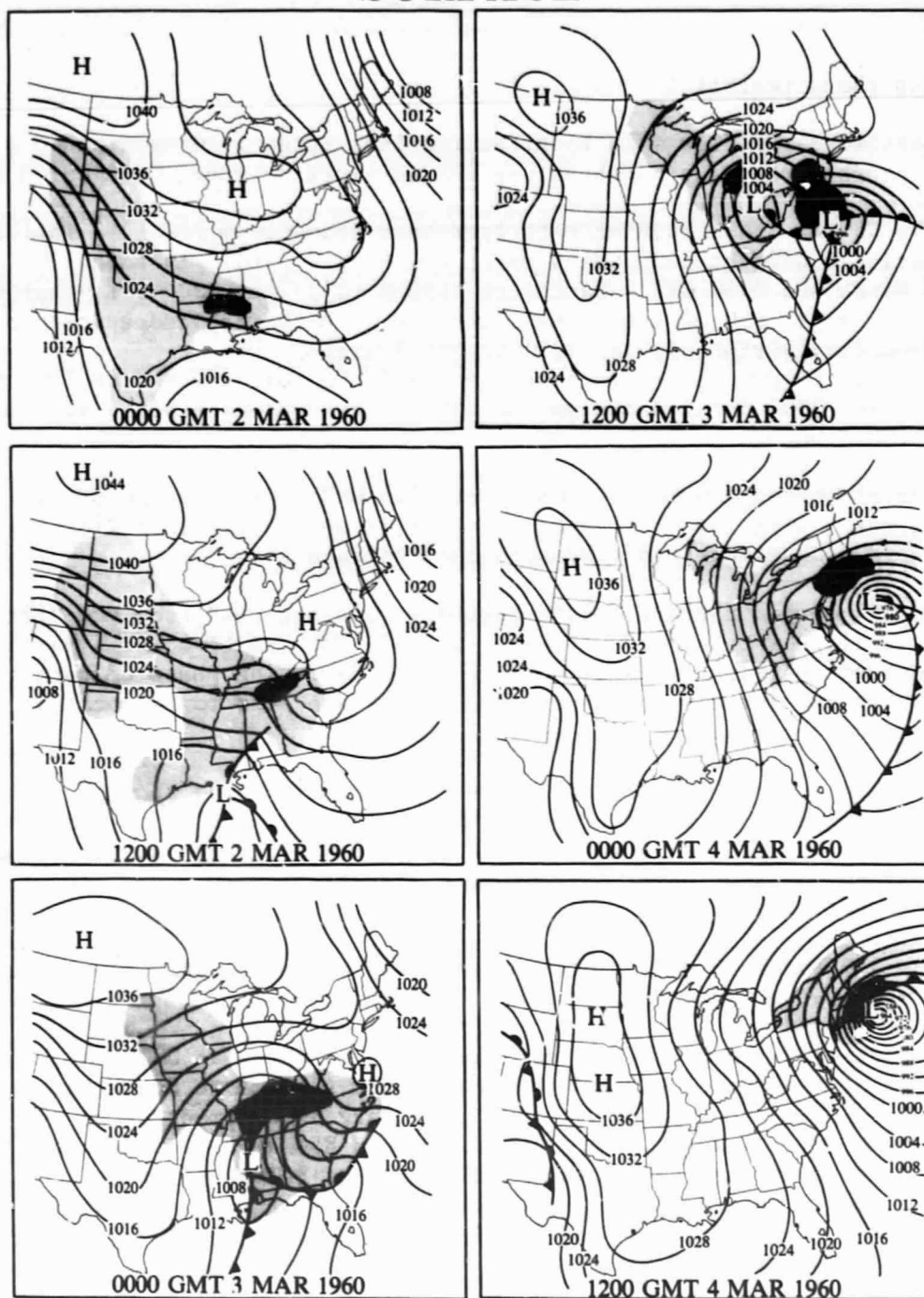


Fig. 2. Surface frontal and weather analyses for 0000 GMT 2 March, 1200 GMT 2 March, 0000 GMT 3 March, 1200 GMT 3 March, 0000 GMT 4 March, and 1200 GMT 4 March 1960. Charts include high and low pressure centers, isobars (solid, mb, in 4 mb increments), and precipitation (shaded; moderate to heavy precipitation is shaded darker).

850 mb characteristics

- o Northwesterly flow with temperatures less than -10°C maintained a cold pattern across the northeastern United States through 0000 GMT 3 March.
- o The 850 mb low deepening rate increased from $-60 \text{ m (12 h)}^{-1}$ in the 12 h period ending at 0000 GMT 3 March to $-90 \text{ m (12 h)}^{-1}$ by both 1200 GMT 3 March and 0000 GMT 4 March, to $-150 \text{ m (12 h)}^{-1}$ by 1200 GMT 4 March. The increase in 850 mb deepening coincided with the rapid deepening of the secondary surface low after 0000 GMT 3 March.
 - Local height falls increased in magnitude near the 850 mb low center after 0000 GMT 3 March as the 850 mb low center deepened at a more rapid pace.
- o The elongated 850 mb low center at 1200 GMT 3 March suggests two centers, with the southeastern extension over Virginia reflecting the rapid redevelopment of the secondary surface low.
- o An "S"-shaped pattern to the isotherms was observed from the Middle-Atlantic coast to the Gulf Coast at 0000 GMT and 1200 GMT 3 March, in conjunction with the start of the rapid deepening phase of both the 850 mb and surface lows. The 850 mb low appeared to be located just upwind of the apex of the thermal ridge.
- o A ribbon of concentrated temperature gradients moved from the southern United States on 2 March to the Middle Atlantic states by 3 March where the thermal gradients intensified by 1200 GMT 3 March as the secondary surface low developed. Strong warm advections were associated with the enhanced gradients.
- o The 0°C isotherm was colocated generally with the position of the 850 mb low center at 0000 GMT and 1200 GMT 3 March.
- o A southerly low-level jet was observed over Texas at 0000 GMT 2 March, over Alabama at 1200 GMT 2 March and from Alabama to South Carolina by 1200 GMT 3 March, prior to rapid secondary development. The jet formed as the primary surface low and associated 850 mb center deepened slowly.
 - Winds over the southeastern United States increased from 15 to 20 m s^{-1} to over 25 m s^{-1} by 0000 GMT 3 March and were located immediately upwind of an outbreak of moderate to heavy precipitation from Tennessee to southwestern Virginia.
- o Heavy snow along the Middle Atlantic coast developed by 1200 GMT 3 March as the secondary low formed, local height falls increased in magnitude, the temperature gradient amplified and a low-level east to southeasterly jet to the north of the 850 mb low center formed. The combination of the enhanced temperature gradients and increasing low-level winds intensified the warm advection and moisture transports into the developing precipitation region in the Middle Atlantic states.

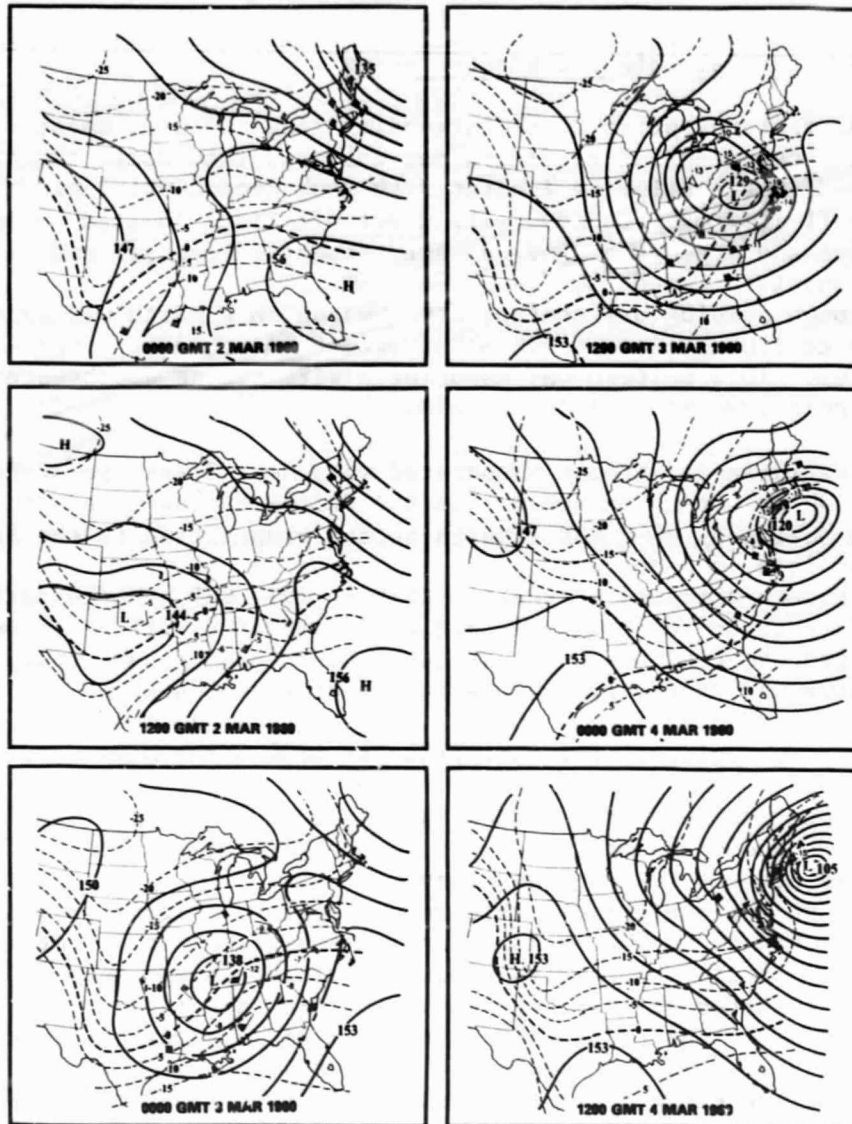


Fig. 3. The 850 mb analyses for 0000 GMT 2 March, 1200 GMT 2 March, 0000 GMT 3 March, 1200 GMT 3 March, 0000 GMT 4 March, and 1200 GMT 4 March 1960. The analyses include geopotential heights (solid, 150 = 1500 m), isotherms (dashed, $^{\circ}\text{C}$), selected values of maximum 12 hourly geopotential height falls ($-6 = -60 \text{ m (12 h)}^{-1}$), and selected wind reports (flags represent speeds of 25 m s^{-1} ; barbs represent speeds of 5 m s^{-1} ; and half-barbs represent speeds of 2.5 m s^{-1}).

500 mb geopotential height characteristics

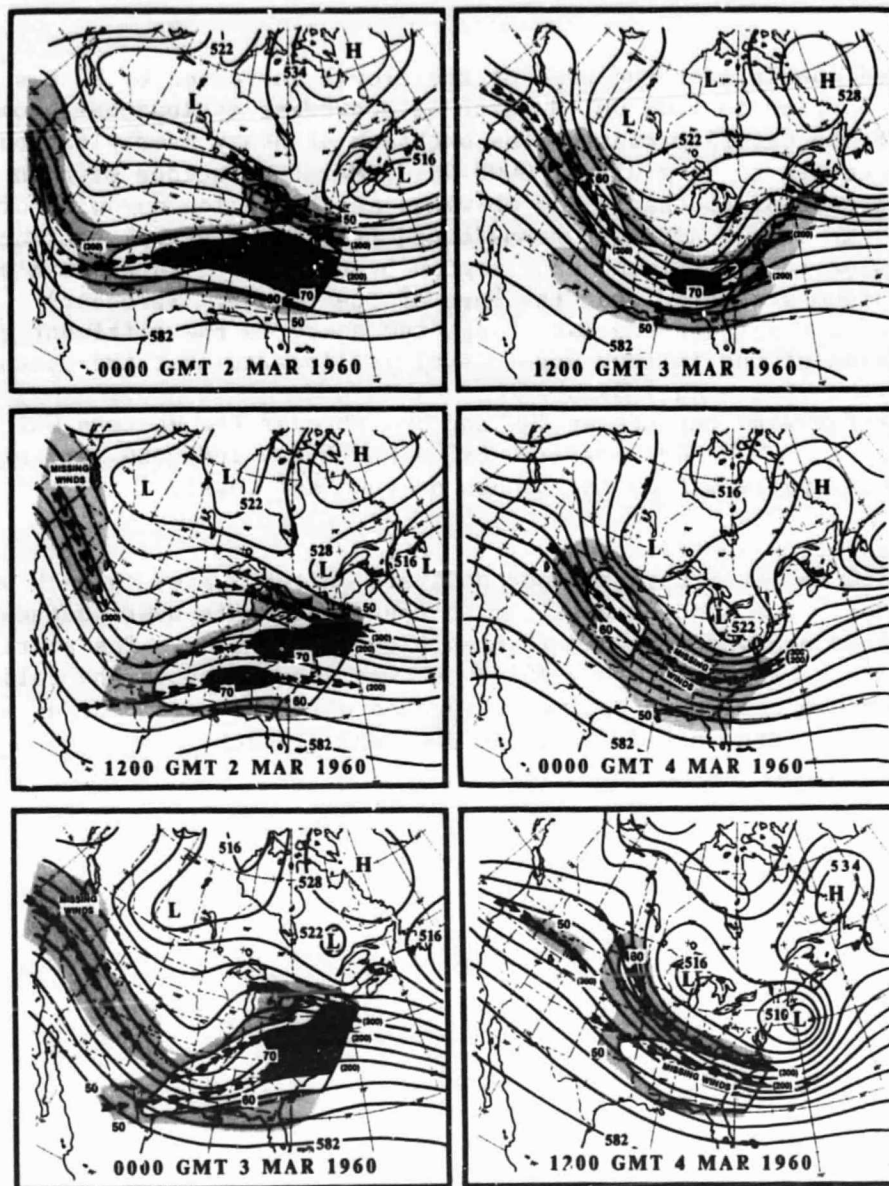
- o General features prior to cyclogenesis along the East Coast
 - Strong geopotential gradients and westerly flow dominated the United States prior to 3 March with weak geopotential gradients and cut-off flow over Canada, with a cut-off ridge located between Quebec and Greenland, and cut-off troughs in central and southeastern Canada.
 - A trough passing off southeastern Canada on 2 March was associated with confluent flow at 500 mb across the northeastern United States. This pattern was associated with strong northwesterly flow and cold advection at low levels.
- o Characteristics of trough associated with East Coast cyclogenesis
 - The 500 mb trough extended from the United States-Canadian border into Mexico by 0000 GMT 3 March before propagating to the East Coast late on 3 March.
 - The trough attained a negative tilt by 0000 GMT 3 March during the early phase of cyclogenesis and was associated with an increase of the geopotential height gradients at the base of the trough as both primary and secondary low pressure centers intensified.
 - Diffluence downwind of the trough axis was pronounced during rapid secondary cyclogenesis, especially at 1200 GMT 3 March and 0000 GMT 4 March.
 - A closed 500 mb center formed during rapid cyclogenesis by 0000 GMT 4 March and deepened rapidly on 4 March as the surface low moved slowly off the New England coast.
 - Although the surface cyclonic development was significant in this case, changes in 500 mb trough/ridge amplitude were relatively small. Little increase in amplitude of the trough and upstream ridge occurred prior to cyclogenesis, but there was an increase in amplitude of the trough and downstream ridge across the northern United States during secondary cyclogenesis on 3 March.
 - The half-wavelength between trough and downstream ridge appeared to shorten at two times:
 - (A) 1200 GMT 2 March--during primary cyclogenesis.
 - (B) 0000 GMT 4 March--during secondary cyclogenesis.

Upper-level jet characteristics

- o Jet streak characteristics of the cyclone-associated trough and flanking ridges
 - The jet stream traversed east to west across the entire country on 2 and 3 March.
 - An intense 200 mb subtropical jet streak was located in the downstream ridge across the eastern United States (70 m s^{-1}) prior to cyclogenesis, above the area of heavy snowfall associated with the inverted trough in the Tennessee Valley on 2 March. Wind speeds in the subtropical jet at the ridge crest do not appear to increase significantly with time.

- Wind speeds near the base of the trough increased by 20 m s^{-1} in 24 h prior to 1200 GMT 3 March as secondary cyclogenesis commenced off the Carolina coast. The outbreak of heavy precipitation from Tennessee to Virginia at 0000 GMT 3 March coincided with an increase of southerly 850 mb winds as the region downwind of the 500 mb trough axis was transformed from a jet streak entrance region to a diffluent exit region by 1200 GMT 3 March as a wind maximum was noted near the base of the trough. Secondary cyclogenesis off the East Coast commenced in the diffluent exit region of the intense upper-level jet located over the southeastern United States on 3 March.
- Missing wind reports at 200 and 300 mb over the eastern United States at 0000 GMT and 1200 GMT 4 March may indicate very high winds upstream from the trough on the East Coast.
- o Other jet characteristics
 - A 300 mb jet across the northeastern United States through 0000 GMT 3 March was located upstream of the trough axis over southeastern Canada and was imbedded in highly confluent flow. The confluent entrance region of this polar jet was located above the cold high pressure cell that became entrenched over the east-central and northeastern United States at 0000 GMT 3 March.

500 MB HEIGHTS AND UPPER-LEVEL WINDS



10-13 December 1960

2b. 10-13 DECEMBER 1960

o General Remarks

- The storm was the first of three big snowstorms during the 1960-1961 winter season, and was accompanied by wind gusts of up to 42 m s⁻¹ at Block Island, R.I. and 38 m s⁻¹ at Nantucket, Ma. Temperatures falling below -7°C created blizzard conditions across parts of the Middle Atlantic and New England states.

o Regions with snow accumulations exceeding 10 in (25 cm)

- West Virginia panhandle, extreme northern Virginia, Maryland (except for the lower eastern shore), parts of Delaware, southern and eastern Pennsylvania, New Jersey, southeastern New York, Connecticut, Rhode Island, Massachusetts (except the extreme west), extreme southeastern Vermont, southern New Hampshire, and coastal Maine

o Regions with snow accumulations exceeding 20 in (51 cm)

- scattered locations in northern New Jersey and eastern Massachusetts

o Urban center snowfall amounts:

Washington, D.C.-National Airport	8.5" (22 cm)
Baltimore, Md.	14.1" (36 cm)
Philadelphia, Pa.	14.6" (37 cm)
New York, N.Y.-The Battery	17.0" (44 cm)
Boston, Ma.	13.0" (33 cm)

o Other selected snowfall amounts:

Newark, N.J.	20.4" (52 cm)
Trenton, N.J.	16.6" (42 cm)
Portland, Me.	14.9" (38 cm)
Hartford, Ct.	13.4" (34 cm)
Providence, R.I.	11.2" (28 cm)

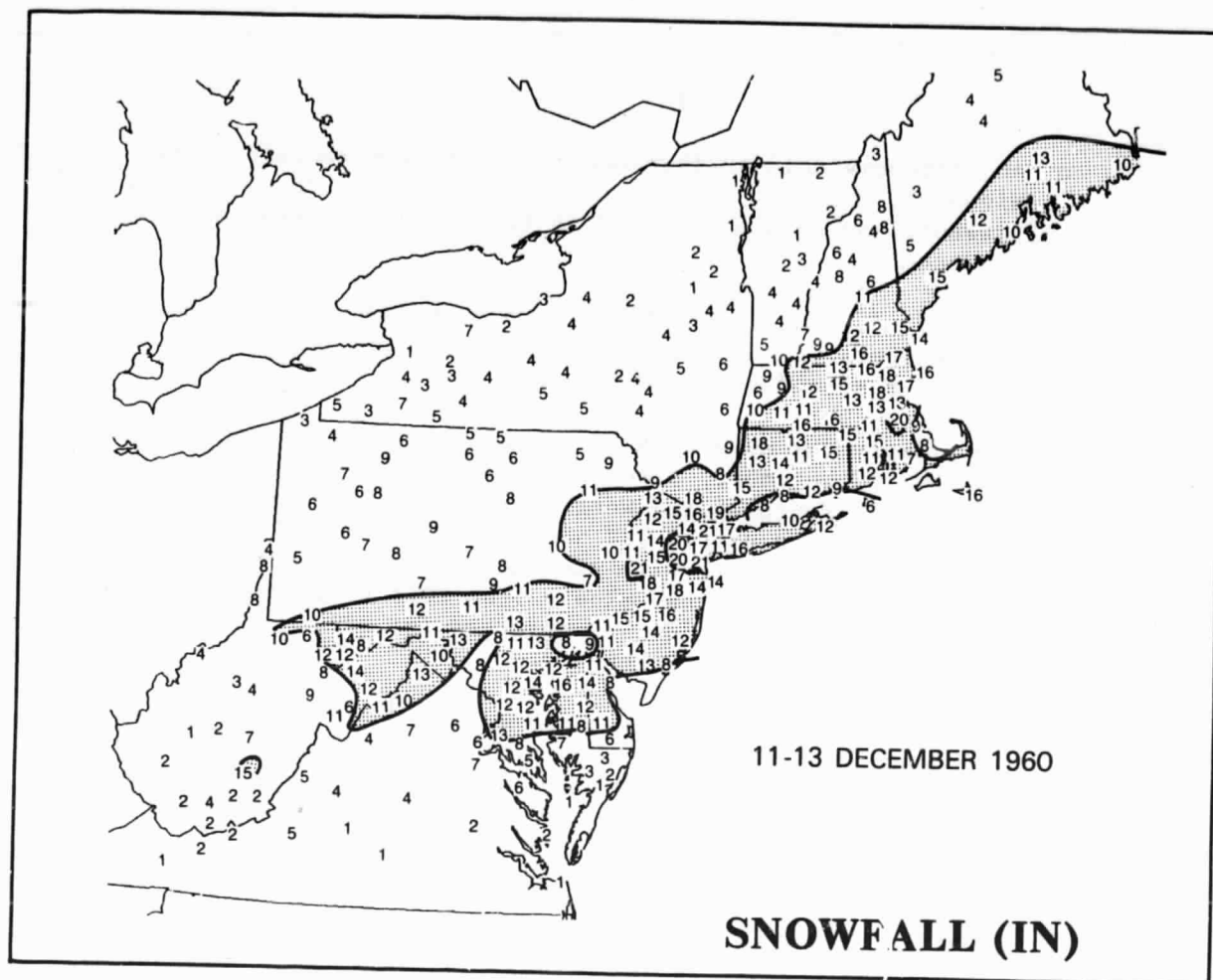


Fig. 5. Total snow accumulations for 11 to 13 December 1960 (in). See Fig. 1 caption for details.

Surface characteristics

- o Type "B" (Miller, 1946)
- o An extremely cold anticyclone (1035 mb) was centered north of Minnesota prior to and during cyclogenesis, with a ridge of high pressure and cold air extending toward New England on 11 December.
- o Cold air damming along the East Coast became pronounced on 11 December, immediately prior to the formation of a coastal front and secondary cyclogenesis.
- o The primary low developed in the western Gulf of Mexico by 1200 GMT 10 December, propagated northward to Oklahoma, then eastward to Kentucky and West Virginia by 0000 GMT 12 December. The low pressure system was associated with light to moderate precipitation amounts with snow accumulations generally less than 12 cm, and deepened slowly from 1012 to 1002 mb during this period. The primary low was observed for only 6 h after the onset of secondary cyclogenesis.
- o The secondary low began to develop around 1800 GMT 11 December over South Carolina along a rapidly evolving coastal front. The low moved off the Atlantic coast after passing near Cape Hatteras, N.C. at 0000 GMT 12 December, moving northeastward at approximately 16 to 17 m s^{-1} , and deepened rapidly over a 24 h period on 12 December, reaching 966 mb by 0000 GMT 13 December.
- o Sea-level pressure gradients to the north of the low center intensified rapidly as the cyclone deepened on 12 December.
- o Unseasonable cold followed the storm with temperatures 10°C below seasonal levels for the next few days across the eastern United States.

SURFACE

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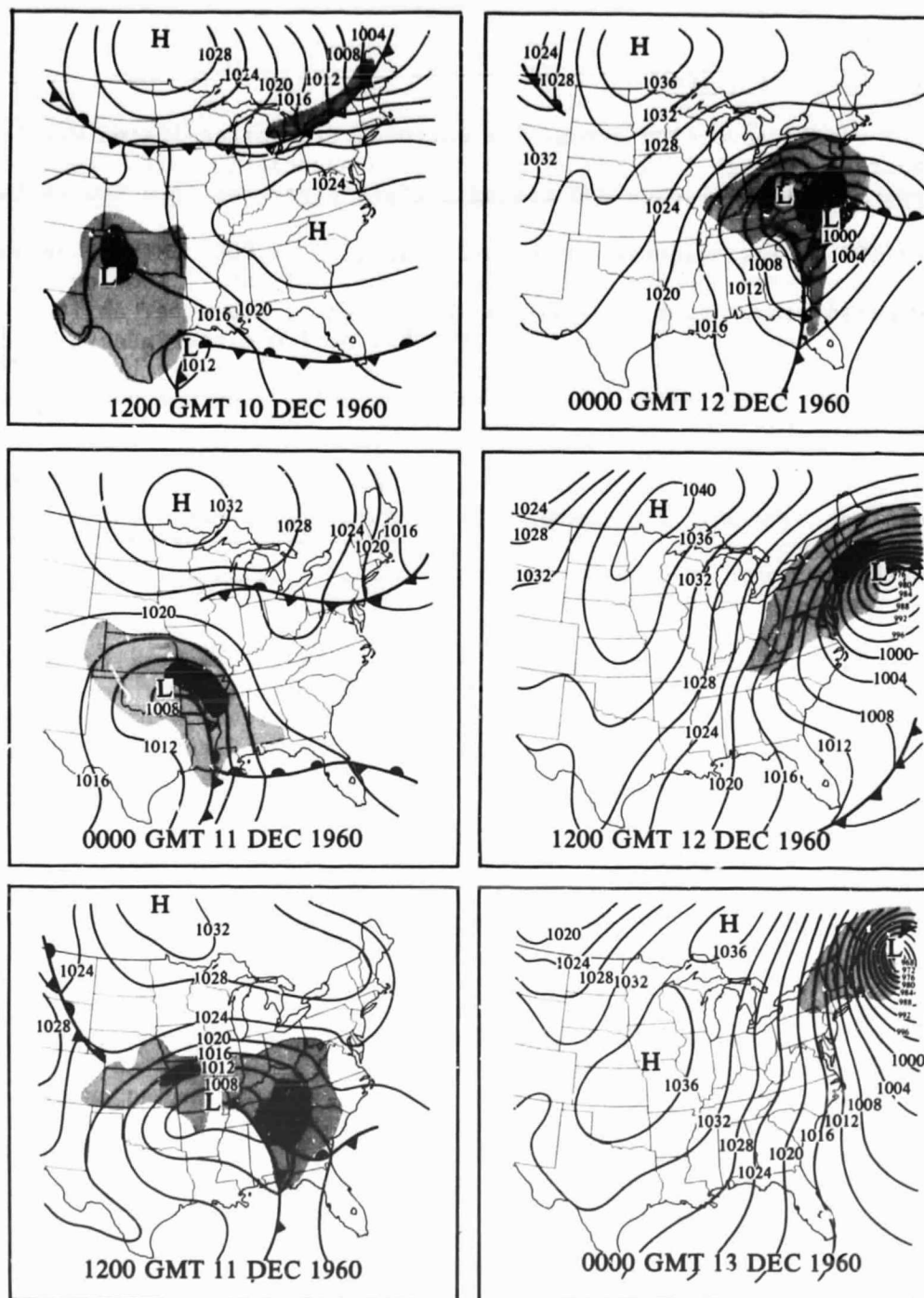


Fig. 6. Surface frontal and weather analyses for 1200 GMT 10 December, 0000 GMT 11 December, 1200 GMT 11 December, 0000 GMT 12 December, 1200 GMT 12 December, and 0000 GMT 13 December 1960. See Fig. 2 caption for details.

850 mb characteristics

- o Strong cold advection across the northeastern United States was observed through 1200 GMT 11 December in association with pronounced upper-level confluence and rising surface pressures into New England.
- o The 850 mb low deepened and expanded in size at 0000 GMT 11 December as the primary surface low deepened across Oklahoma. The low deepened slowly from 0000 GMT 11 to 0000 GMT 12 December as it moved from Oklahoma to West Virginia. The 850 mb low either redeveloped or rapidly moved toward the coast and deepened explosively by 1200 GMT 12 December, approximately 12 h after secondary surface cyclogenesis was initiated.
- o An "S"-shaped pattern of isotherms became established along the East Coast by 0000 GMT 12 December as secondary cyclogenesis commenced. The S-shaped pattern developed as strong warming occurred along the Southeast Coast while temperatures remained relatively constant in the northeastern United States.
- o The 0°C isotherm remained fairly stationary across West Virginia and Virginia prior to and during secondary cyclogenesis over North Carolina at 0000 GMT 12 December despite significant warm air advection during this period. Prior to this time, the low-level temperature gradient was concentrated in the cold air across the northeastern United States while the thermal gradient across the southeastern United States remained fairly weak. However, the low-level temperature gradient over the Southeast increased at 1200 GMT 11 December and 0000 GMT 12 December as warm advection and a 20 to 25 m s^{-1} low-level jet formed across the southeastern United States.
- o Strong southerly low-level winds developed across the southeastern United States by 11 December. These strong winds developed beneath the diffluent exit region of the upper-level jet system moving along the Gulf coast and appear to be responsible for enhancing moisture transport toward the precipitation area as it expanded toward the eastern United States by 0000 GMT 12 December. Strong southeasterly winds were also observed at 0000 GMT 12 December in the Middle-Atlantic states in advance of the 850 mb low center.

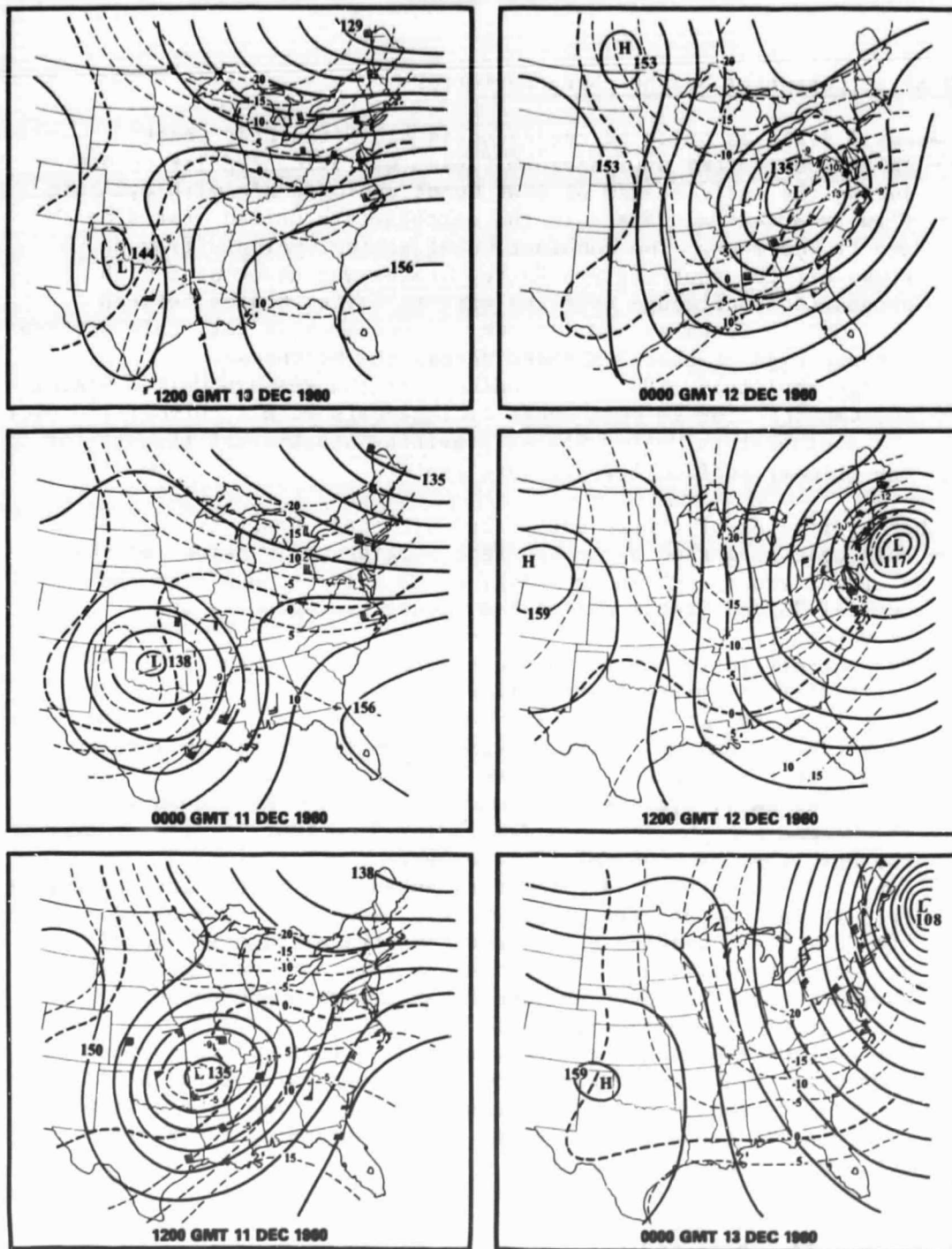


Fig. 7. The 850 mb analyses for 1200 GMT 10 December, 0000 GMT 11 December, 1200 GMT 11 December, 0000 GMT 12 December, 1200 GMT 12 December, and 0000 GMT 13 December 1960. See Fig. 3 caption for details.

500 mb geopotential height characteristics

- o General features prior to cyclogenesis along the East Coast
 - An intense vortex over eastern Canada was evident prior to and during the early stages of East Coast cyclogenesis with cyclonic flow from central Canada to the northeastern United States on 10 and 11 December. The combination of strong cyclonic flow and a ridge off the southeastern United States was associated with pronounced confluence over the eastern United States between 1200 GMT 10 December and 1200 GMT 11 December as very cold surface air and high pressure extended across the Northeast.
 - A high amplitude ridge was located over the western United States and Canada prior to East Coast cyclogenesis with a cut-off low over the southwestern United States providing upper-level support for the primary surface low pressure center.
- o Characteristics of trough associated with East Coast cyclogenesis
 - This case is marked by an apparent merging or "phasing" of the southwestern trough and a "digging" Canadian trough over the central United States during East Coast cyclogenesis on 12 December.
 - The cut-off vortex over the southwestern United States "opened up" as it drifted to the east on 11 December.
 - A separate trough imbedded in the strong cyclonic flow regime moved from central Canada to the midwestern United States by late on 11 December and appears to phase in or merge with the southwestern trough as rapid cyclogenesis commenced off the East Coast.
 - The merged troughs formed a deep, closed-contour low center over the Northeast by 0000 GMT 13 December.
 - Amplitude changes are difficult to assess due to the transformation from vortex to open trough to vortex. However, the amplitude of the "digging" Canadian trough and downstream ridge increased sharply after 0000 GMT 12 December as cold air and high pressure became established over the Great Lakes region and rapid cyclogenesis commenced along the Atlantic coast.
 - The half-wavelength between the closed-contour 500 mb center and downstream ridge decreased prior to cyclogenesis (between 1200 GMT 10 December and 0000 GMT 11 December), but it was difficult to determine if the half-wavelength decreased during the rapid cyclogenesis on 12 December.

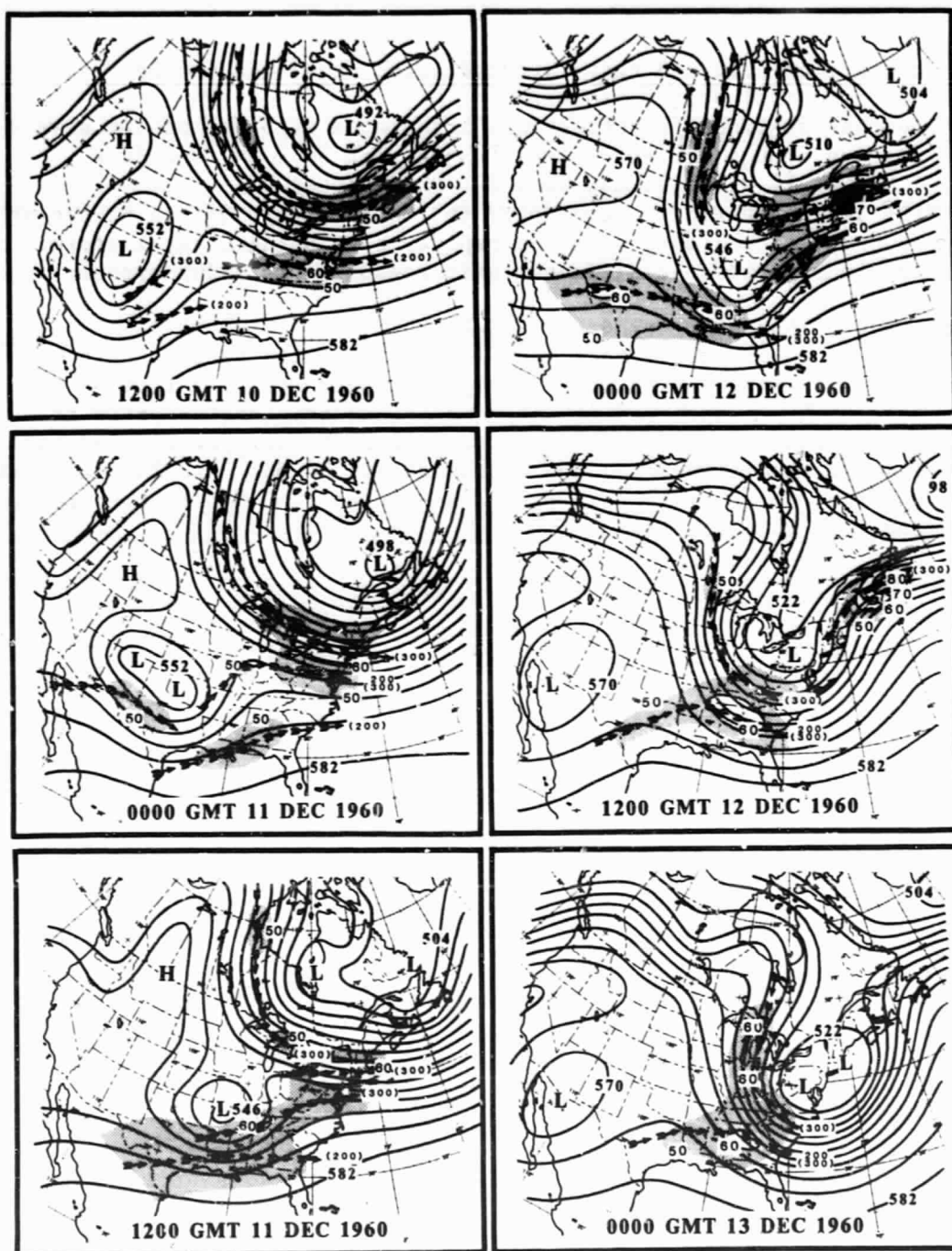
Upper-level jet characteristics

- o The jet streak characteristics of the cyclone-associated troughs and flanking ridges were very complicated₁ for this case.
 - Wind speeds of greater than 50 m s^{-1} increased in areal coverage, with maximum winds increasing to greater than 60 m s^{-1} by 1200 GMT 11 December to the south of the initially closed-center Southwest trough. The increase in wind speed and areal coverage occurred as

the primary low and heavy precipitation developed in the south-central United States.

- Another distinct jet streak was associated with the southeastward digging trough across central Canada with 50 m s^{-1} speeds at 1200 GMT 11 December and 0000 GMT 12 December.
 - The jets appeared to merge over the southeastern United States at 1200 GMT 12 December with the rapidly developing coastal storm located beneath the diffluent exit region of this jet system.
- o Other jet characteristics
- Intense polar jet streaks were located over the northeastern United States in association with highly confluent cyclonic flow as the cold high pressure center extended across this region prior to cyclogenesis. Wind speeds in the polar jet over New England and eastern Canada increased by approximately 20 m s^{-1} in 24 h as East Coast cyclogenesis was in progress between 1200 GMT 11 December and 1200 GMT 12 December.

500 MB HEIGHTS AND UPPER-LEVEL WINDS



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Fig. 8. The 500 mb geopotential height analyses and isotachs of maximum wind speeds for 1200 GMT 10 December, 0000 GMT 11 December, 1200 GMT 11 December, 0000 GMT 12 December, 1200 GMT 12 December, and 0000 GMT 13 December 1960. See Fig. 4 caption for details.

19-20 January 1961

2c. 19-20 JANUARY 1961

o General Remarks

- The "Kennedy Inaugural" snowstorm occurred on the eve of John F. Kennedy's inauguration in Washington, D.C. and was the second of three major East Coast winter storms during the 1960-1961 season. The area of heaviest snowfall was similar in location to the December 1960 storm with blizzard or near-blizzard conditions across the northeastern United States as the cyclone deepened rapidly off the East Coast.

o Regions with snow accumulations exceeding 10 in (25 cm)

- northern Maryland and Delaware, parts of West Virginia and Virginia, southeastern Pennsylvania, New Jersey, southeastern New York, Connecticut, Rhode Island, Massachusetts (except for the northwest corner) and southern sections of New Hampshire and Maine.

o Regions with snow accumulations exceeding 20 in (51 cm)

- scattered parts of eastern Pennsylvania, northern New Jersey, southeastern New York, northwestern Connecticut, northeastern Massachusetts and southern New Hampshire

o Urban center snowfall amounts:

Washington, D.C.-National Airport	7.7" (20 cm)
Baltimore, Md.	8.4" (21 cm)
Philadelphia, Pa.	13.2" (34 cm)
New York, N.Y.-Central Park	9.9" (25 cm)
Boston, Ma.	12.3" (31 cm)

o Other selected snowfall amounts:

Harrisburg, Pa.	18.7" (47 cm)
Worcester, Ma.	18.7" (47 cm)
Nantucket, Ma.	16.0" (41 cm)
Hartford, Ct.	14.2" (36 cm)
Newark, N.J.	13.7" (35 cm)

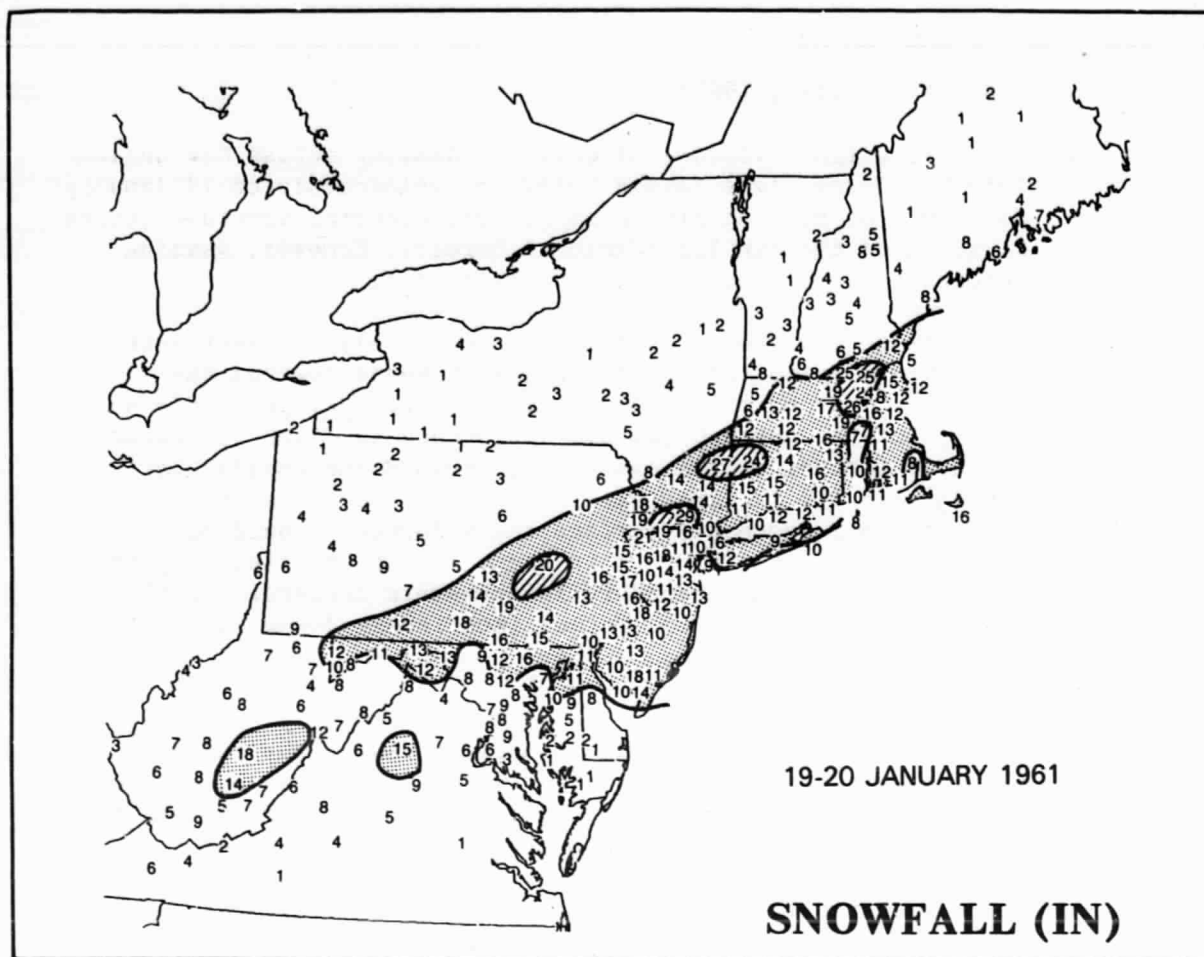


Fig. 9. Total snow accumulations for 19 to 20 January 1961 (in). See Fig. 1 caption for details.

Surface characteristics

- o Type "A" (Miller, 1946)
- o There is slight evidence of cold air damming across New England into New Jersey immediately prior to cyclogenesis on 19 January, as a 1024 mb cell of high pressure was anchored several hundred km north of the New York-Canadian border. However, damming appears to be a minor aspect for this case.
- o The surface low seemed to follow a relatively straight path, even over the Appalachian range, as it moved towards the Atlantic Coast on 19 January. Type "B" redevelopment did not occur, but the surface low had a tendency to "jump" or reform slightly further to the east as it crossed the Appalachian Mountains on 19 January. Miller's (1946) study seemed to indicate that secondary surface redevelopment should be classified as type "B" only if there is a discontinuous path between primary and secondary low pressure centers. In this case, the redeveloped low formed immediately downwind of its prior location.
- o The cyclone moved rapidly, crossing approximately 700 km every 12 h. The rapid movement was a primary reason why snowfall amounts were generally less than 20 in (50 cm), since heaviest snows fell over a 12 h period or less. The forward movement of the storm may have slowed slightly off the New England coast.
- o There was no evidence of coastal frontogenesis, which could be related, in part, to the speed with which this system developed and moved across the East Coast.
- o The cyclone deepened rapidly from 1200 GMT 19 January through 0000 GMT 21 January, in which the central pressure fell 43 mb over a 24 h period. The storm deepened to 964 mb well to the east of New England late on 20 January.
- o The rapid intensification of the surface low center coincided with the rapid expansion of the precipitation shield on 19 January. Virtually no precipitation was occurring at 0000 GMT 19 January, with light snows across the Ohio Valley by 1200 GMT 19 January. Precipitation amounts increased dramatically in the following 12 to 24 h in the Middle Atlantic states northeastward to New England.
- o High pressure following the cyclone plunged southward to Texas while a reinforcing cold anticyclone followed across the Plains states.

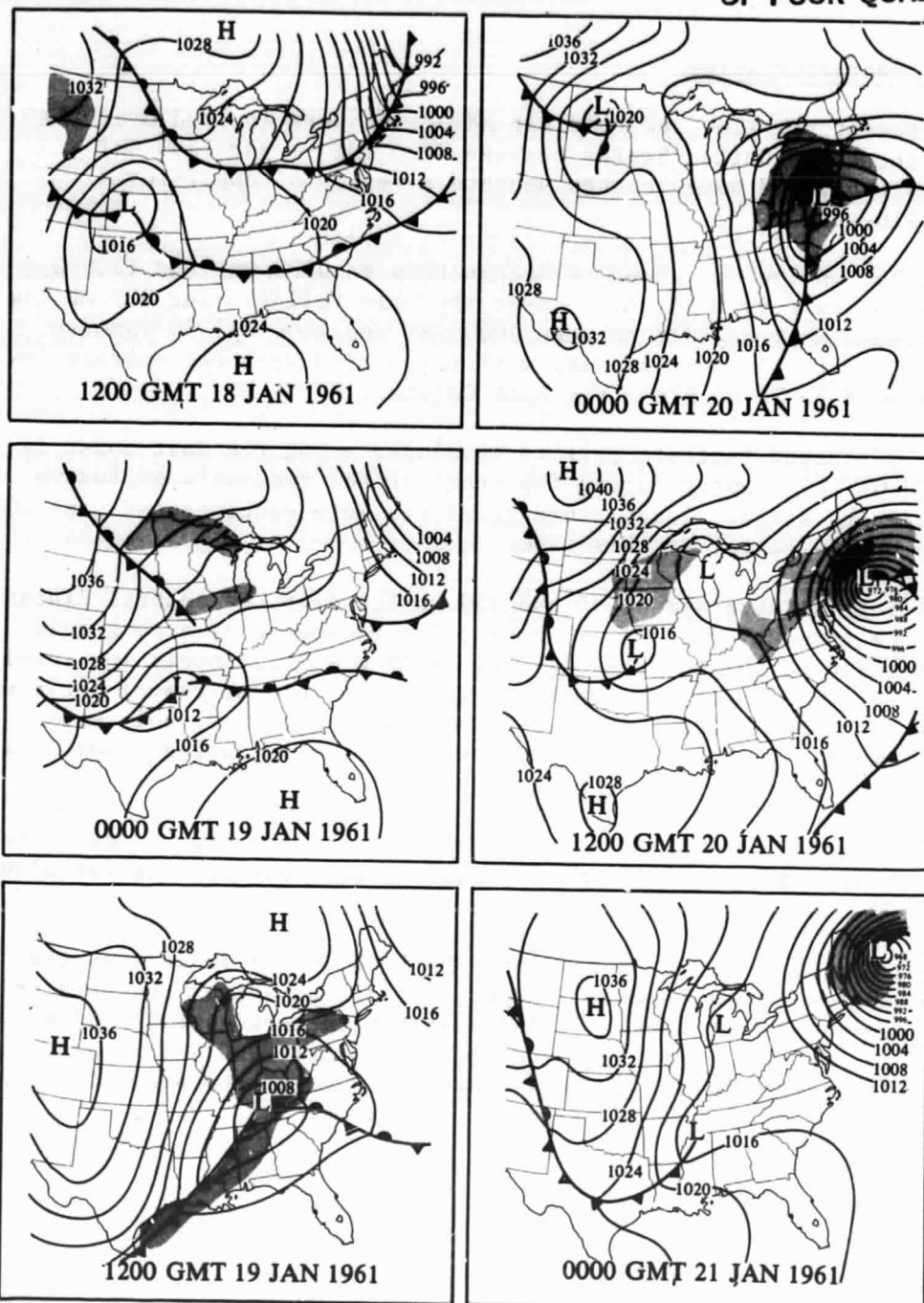


Fig. 10. Surface frontal and weather analyses for 1200 GMT 18 January, 0000 GMT 19 January, 1200 GMT 19 January, 0000 GMT 20 January, 1200 GMT 20 January, and 0000 GMT 21 January 1961. See Fig. 2 caption for details.

850 mb characteristics

- o Northwestern flow and cold air advection were located over the northeastern United States between 1200 GMT 18 and 1200 GMT 19 January and were located beneath a region of upper-level confluence.
- o The 850 mb low commenced to deepen between 0000 GMT and 1200 GMT 19 January ($-90 \text{ m (12 h)}^{-1}$) over the Ohio Valley. The 850 mb low deepened most rapidly between 0000 GMT and 1200 GMT 20 January ($-210 \text{ m (12 h)}^{-1}$) coinciding with the period when the surface low deepened by 24 mb along the East Coast.
- o An "S"-shaped isotherm pattern developed along the East Coast by 0000 GMT 20 January during the start of the cyclone's explosive deepening stage. Temperature gradients were concentrated near the 850 mb low center at this time.
- o The initial development of the 850 mb low over the central Plains states through 0000 GMT 19 January was dominated by strong cold advection to the rear of the low. A 25 m s^{-1} northerly low-level jet was located beneath the entrance region of an upper-level jet across the Southern Plains. To the east of the 850 mb low, only weak southwesterly flow and warm advection are noted during a period when little precipitation was reported.
- o No appreciable easterly flow to the north of the 850 mb low center was observed until 0000 GMT 20 January, when the cyclone was along the East Coast.
- o Warm advection patterns developed by 1200 GMT 19 January as the 850 mb low center began to deepen, but the advecting southwesterly winds were rather weak. Strong easterly to northeasterly flow ahead of the low center did not develop until after 0000 GMT 20 January, possibly contributing to the intensification of the precipitation rates during the latter stages of the storm.

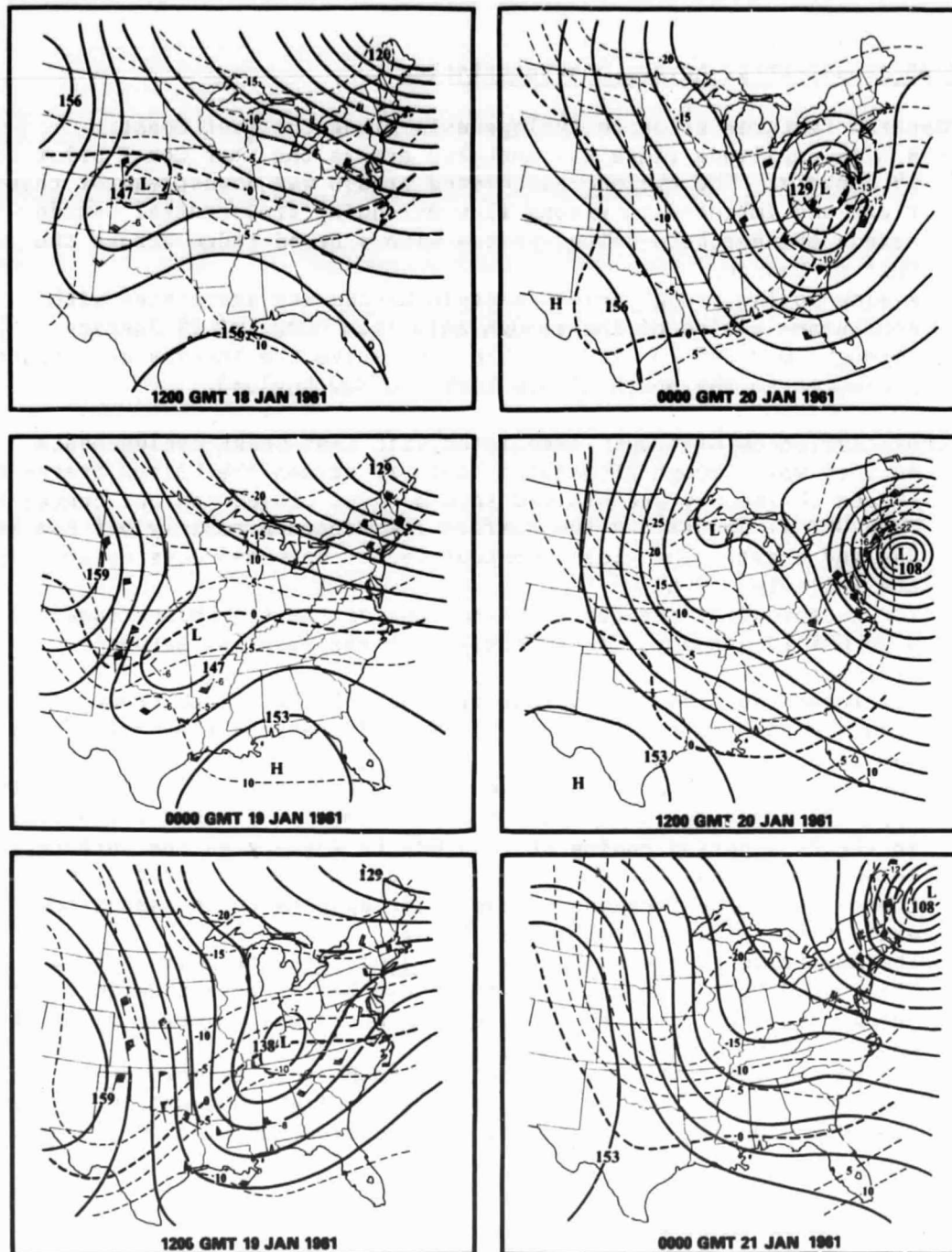


Fig. 11. The 850 mb analyses for 1200 GMT 18 January, 0000 GMT 19 January, 1200 GMT 19 January, 0000 GMT 20 January, 1200 GMT 20 January, and 0000 GMT 21 January 1961. See Fig. 3 caption for details.

500 mb geopotential height characteristics

- o General features prior to cyclogenesis along the East Coast
 - A high amplitude ridge was anchored across the West Coast prior to 19 January. The cyclone-associated trough was downstream of this ridge and imbedded in strong flow extending from central Canada across the northern United States with a broad ridge across the Gulf of Mexico.
 - A slow-moving trough across eastern Canada was associated with confluence upwind of the trough axis from 0000 GMT 19 January through 0000 GMT 20 January that lies above the increasing surface pressures to the north of New York and New England.
- o Characteristics of trough associated with East Coast cyclogenesis
 - An open wave trough propagated eastward across the United States on 19 and 20 January and evolved into a deep, closed-contour center by 0000 GMT 21 January as the surface low deepened rapidly off the New England coast. The closed-contour center deepened considerably in the following 12 h.
 - The geopotential gradients at the base of the trough increased at 0000 GMT 20 January, concurrently with the onset of strong cyclogenesis.
 - Diffluence and the development of a negatively tilted trough occurred simultaneously by 1200 GMT 20 January as the surface low was deepening rapidly.
 - The amplitude of the trough over the central United States and its upstream flanking ridge along the West Coast increased dramatically in the 24 h period ending at 1200 GMT 19 January as the surface low moved from Kansas to Tennessee. The amplitude increased slowly thereafter. The increase of amplitude appears to be associated with strong ridging on the West Coast.
 - The amplitude of the trough and its downstream ridge increased after 1200 GMT 19 January, as the ridge became better defined off the New England coast as rapid cyclogenesis was underway along the coast.
 - The half-wavelength between the the trough and its downstream ridge over the eastern United States decreased after 0000 GMT 19 January, especially during the period of rapid cyclogenesis on 20 January.

Upper-level jet characteristics

- o Jet streak characteristics of the cyclone-associated trough and flanking ridges
 - At 1200 GMT 18 January, 50 m s^{-1} wind speeds at 200 and 300 mb were found over Montana upwind of the trough axis and a broader area downwind of the trough.
 - By 0000 GMT 19 January, maximum speeds had increased to over 60 m s^{-1} and were found from near the base of trough and eastward, with evidence of multiple jet streak structure.

- This region of high wind speeds expanded eastward at 1200 GMT 19 January near the developing ridge axis over the eastern half of the United States at a time when the surface low and expanding precipitation shield are evident over the Ohio and Tennessee Valleys.
 - By 0000 GMT 20 January, wind speeds increased to 70 m s^{-1} both upwind and downwind of the trough axis at 200 mb as the wavelength of the trough/downstream ridge system decreased and geopotential gradients increased. The rapid cyclogenesis over Virginia at 0000 GMT 20 January appears to occur in the diffluent exit region of the amplifying jet streak extending up the Carolina coast and in the entrance region of a weaker jet embedded within the confluent flow over New England.
 - Wind speeds amplified greatly upwind of the trough axis at 0000 GMT 21 January over the southeastern United States as the surface low moved east of New England with speeds exceeding 90 m s^{-1} .
- o Other jet characteristics
- Prior to cyclogenesis, confluent flow and a polar jet streak extended across the Great Lakes to a position off the southern New England coastline at a time when a cold surface high pressure system influenced the Great Lakes region and New England states.

500 MB HEIGHTS AND UPPER-LEVEL WINDS

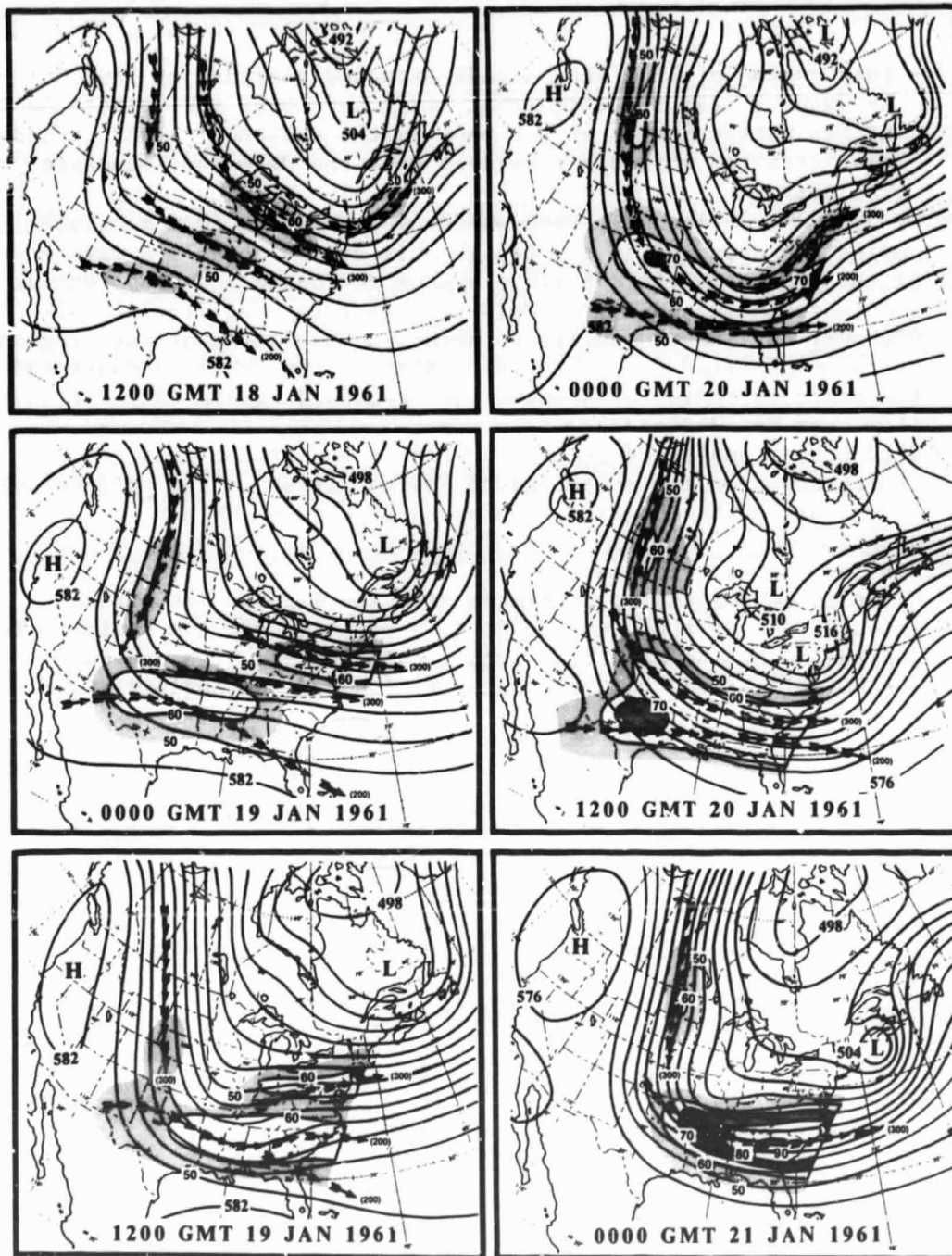


Fig. 12. The 500 mb geopotential height analyses and isotachs of maximum wind speeds for 1200 GMT 18 January, 0000 GMT 19 January, 1200 GMT 19 January, 0000 GMT 20 January, 1200 GMT 20 January, and 0000 GMT 21 January 1961. See Fig. 4 caption for details.

3-4 February 1961

2d. 3-4 FEBRUARY 1961

o General Remarks

- The third major snowstorm of the 1960-1961 season occurred at the end of one of the most prolonged cold spells across the northeastern United States and produced near-record snow cover since snow fell on unmelted accumulations from previous storms. The storm produced paralyzing gale to hurricane force winds on the coast (43 m s⁻¹ gust at Blue Hill Observatory, Milton, Ma.; 41 m s⁻¹ gust at Block Island, R.I.; 24 m s⁻¹ fastest mile at New York City-Central Park--highest ever for February). Temperatures rising to near freezing during the storm produced heavy, wet snow accumulations along the coast.

o Regions with snow accumulations exceeding 10 in (25 cm)

- panhandle of West Virginia, parts of northern Virginia and northern Maryland, Pennsylvania, central and southern New York, central and northern New Jersey, Connecticut, Rhode Island, Massachusetts, southern Vermont, and New Hampshire

o Regions with snow accumulations exceeding 20 in (51 cm)

- northern Pennsylvania, central New York, extreme southeastern New York, Long Island, northern New Jersey, scattered portions of New England

o Urban center snowfall amounts:

Washington, D.C.-National Airport	8.3" (21 cm)
Baltimore, Md.	10.7" (27 cm)
Philadelphia, Pa.	10.3" (26 cm)
New York, N.Y.-Kennedy Airport	24.0" (61 cm)
New York, N.Y.-La Guardia Airport	19.0" (48 cm)
Boston, Ma.	14.4" (37 cm)

o Other selected snowfall amounts:

Cortland, N.Y.	40.0" (102 cm)
Newark, N.J.	22.6" (57 cm)
Worcester, Ma.	18.8" (46 cm)
Providence, R.I.	18.3" (45 cm)
Allentown, Pa.	17.3" (44 cm)

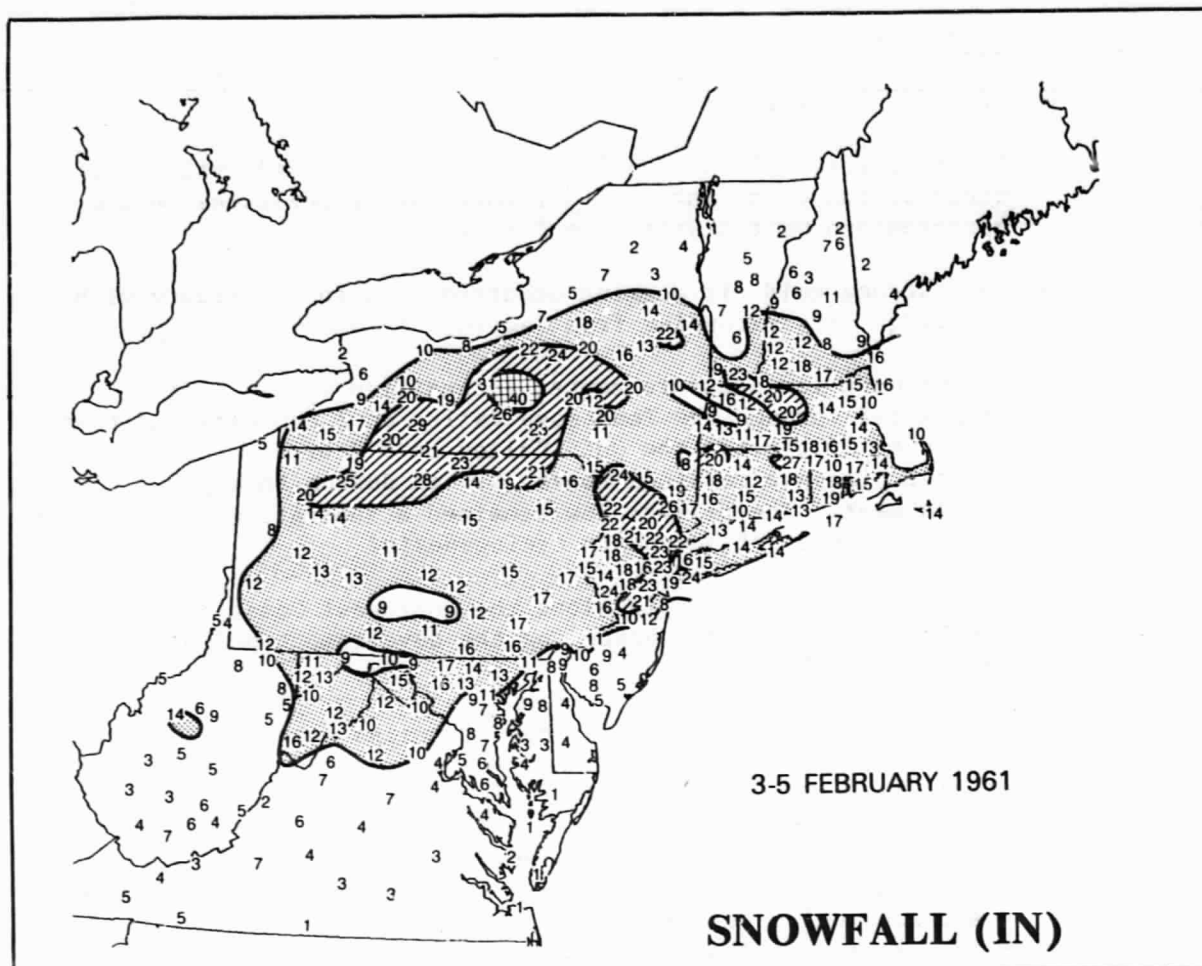


Fig. 13. Total snow accumulations for 3 to 5 February 1961 (in). See Fig. 1 caption for details.

Surface characteristics

- o Type "B" (Miller, 1946)
- o A large, very cold anticyclone (1048 mb) preceded cyclogenesis north of the Great Lakes with record-low temperatures in the northeastern United States on 2 February.
- o Very strong cold air damming occurred on 2 to 3 February with the ridge axis extending from New York to Georgia-Florida.
- o The primary low pressure center intensified slowly as it propagated through the Tennessee Valley on 2 February and then filled as it reached the Ohio Valley on 3 February. The low's central pressure remained above 1010 mb during this phase of development. The primary low remained a separate entity for 9 h after the onset of secondary cyclogenesis.
- o A coastal front developed along the Southeast Coast on 3 February immediately preceding the development of the secondary cyclone.
- o The secondary low formed off South Carolina between 1200 GMT 3 February and 0000 GMT 4 February and deepened rapidly off the Middle Atlantic Coast on 4 February.
 - The low deepened from 1008 mb off Norfolk, Va. at 0000 GMT 4 February to 992 mb off the New Jersey coast in 12 h with most of the deepening occurring between 1200 GMT 3 February and 1200 GMT 4 February.
 - The primary cyclone merged with the secondary center along the New Jersey coast by 1200 GMT 4 February.
 - The secondary center moved northeastward paralleling the coast through 1200 GMT 4 February and then moved to the east during the next 12 h period.
 - Large gradients of sea-level pressure formed to the north of the rapidly deepening secondary low on 4 February as heavy snow and strong northeasterly winds developed from northern Virginia to southern New England.
- o Both primary and secondary lows were relatively slow movers, averaging 11 to 12 m s⁻¹.

SURFACE

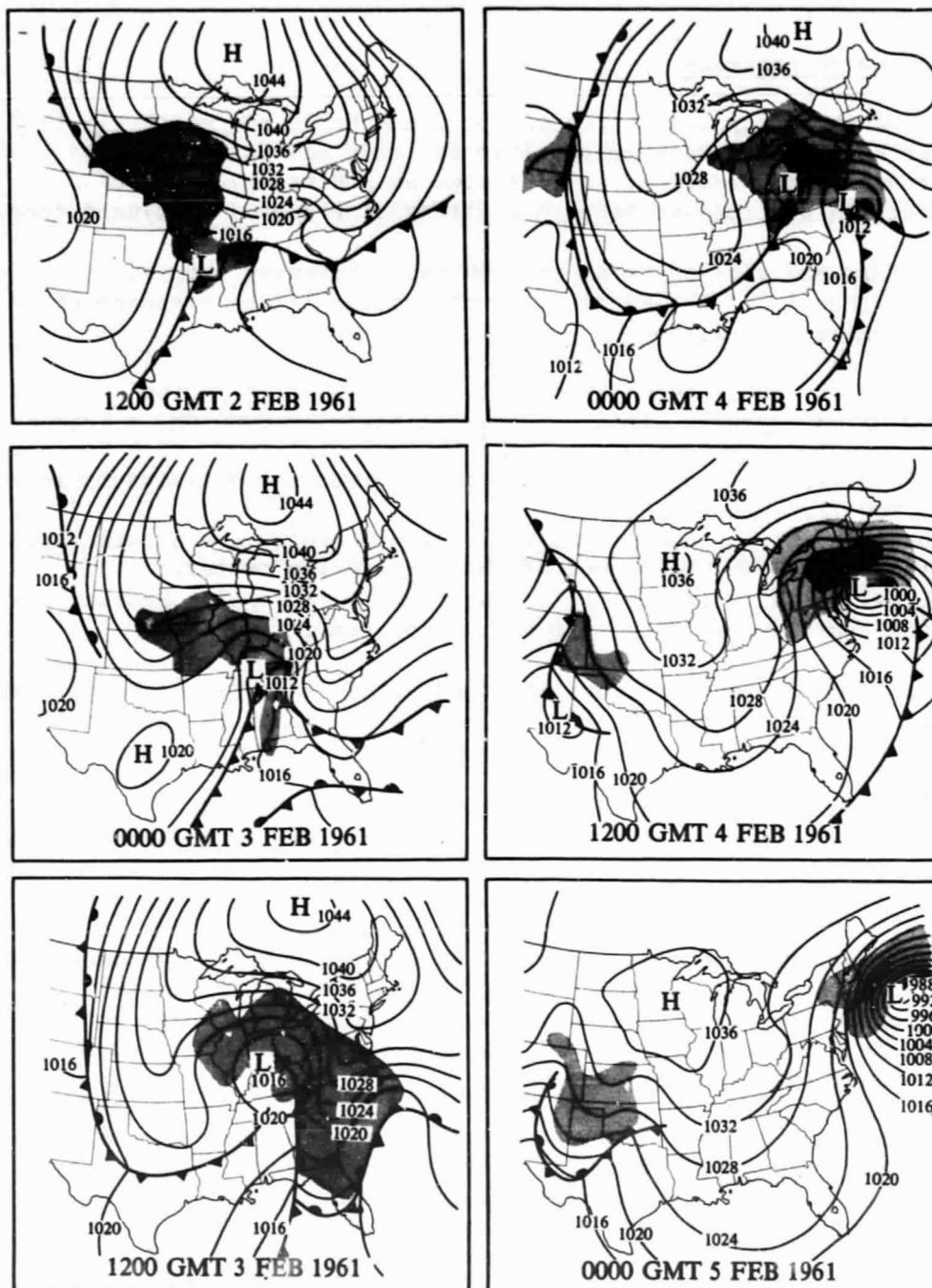


Fig. 14. Surface frontal and weather analyses for 1200 GMT 2 February, 0000 GMT 3 February, 1200 GMT 3 February, 0000 GMT 4 February, 1200 GMT 4 February, and 0000 GMT 5 February 1961. See Fig. 2 caption for details.

850 mb characteristics

- o An 850 mb anticyclone north of the Great Lakes and northerly flow over New England were responsible for cold advection into the Northeast and Middle Atlantic states on 2 February. The cold advection was located beneath a strong upper-level confluent zone.
- o Isotherm and wind patterns at 1200 GMT 2 February suggest frontogenesis in the Middle Atlantic states in the presence of stretching deformation.
- o The 850 mb low center deepened slowly in the 12 h period ending at 0000 GMT 3 February, then weakened slightly by 0000 GMT 4 February before deepening explosively in 12 h ending at 1200 GMT 4 February ($-240 \text{ m (12 h)}^{-1}$) as the surface cyclone was intensifying rapidly off the New Jersey coast.
 - Dual 850 mb low centers at 1200 GMT 4 February are a reflection of the coastal redevelopment of the surface low center.
 - Local height falls amplified markedly by 1200 GMT 4 February with the rapid deepening of the 850 mb low center.
- o The 850 mb low centers were imbedded within a low-level baroclinic zone that extended from the Central Plains states to the Middle Atlantic coast.
- o An "S"-shaped isotherm pattern developed along the East Coast at 1200 GMT 3 February and 0000 GMT 4 February as the secondary cyclone was forming.
- o The 0°C isotherm was displaced to the south and east of the low center prior to secondary cyclogenesis by 1200 GMT 3 February. It appears that strong warm advection had shifted from near the low center to the East Coast at this time. The 0°C isotherm became situated closer to the 850 mb low center by 0000 GMT 4 February with secondary cyclogenesis underway.
- o A southeasterly to easterly low-level jet formed across the Middle Atlantic states by 0000 GMT 4 February in association with secondary cyclogenesis and a shift of the local height falls from the Midwest to the East Coast. This jet appeared to enhance the moisture transport into the developing band of heavy precipitation along the East Coast.

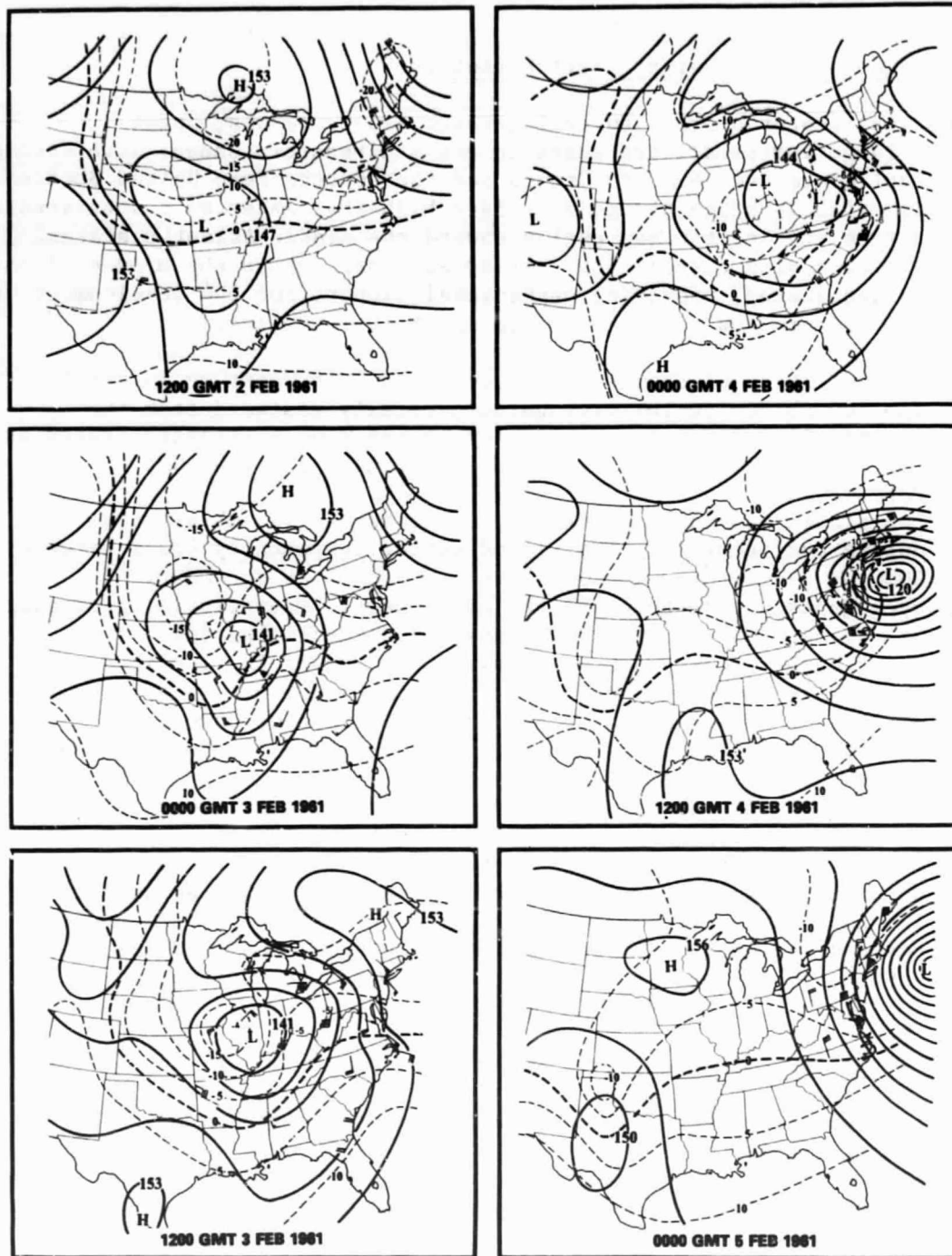


Fig. 15. The 850 mb analyses for 1200 GMT 2 February, 0000 GMT 3 February, 1200 GMT 3 February, 0000 GMT 4 February, 1200 GMT 4 February, and 0000 GMT 5 February 1961. See Fig. 3 caption for details.

500 mb geopotential height characteristics

- o General features prior to cyclogenesis along the East Coast
 - A large vortex drifted eastward off southeastern Canada with strong confluence over eastern Canada and the northeastern United States immediately above the cold surface high that extended southeastward across the Great Lakes region toward the Middle Atlantic states.
 - A slow-moving cut-off low drifted eastward across the middle of the United States, providing upper-level support for the development of the primary low pressure system in the Ohio Valley.
- o Characteristics of trough associated with East Coast cyclogenesis
 - The 500 mb low center propagated generally eastward from the central Plains to the Ohio Valley to the Middle Atlantic states in the 48 h period between 1200 GMT 2 February and 1200 GMT 4 February.
 - The trough maintained a closed low center at 500 mb prior to and during cyclogenesis. The closed center deepened by 120 m between 0000 GMT 4 February and 0000 GMT 5 February as secondary cyclogenesis commenced off the East Coast. Geopotential gradients at the base of the trough increased during this period.
 - The trough/ridge system was slow moving and of low amplitude and short wavelength.
 - Diffluence downwind of the trough axis became pronounced at 0000 GMT and 1200 GMT 4 February as the trough became negatively tilted during secondary cyclogenesis.
 - Very little change in the amplitude of the trough was observed as the primary surface low developed in the Ohio Valley. A small increase in amplitude between the trough and downstream ridge occurred between 1200 GMT 2 February and 0000 GMT 4 February.
 - The half-wavelength between trough and downstream ridge appear to decrease slightly between 1200 GMT 3 February and 1200 GMT 4 February as the trough propagated toward the East Coast.

Upper-level jet characteristics

- o Jet streak characteristics of the cyclone-associated trough and flanking ridges
 - A subtropical jet with speeds exceeding 70 m s^{-1} was located in the downstream ridge off the Southeast Coast through 1200 GMT 3 February.
 - A weaker polar jet propagated into the base of the trough by 0000 GMT 3 February as the primary low developed immediately east of the trough axis in the south-central United States and as the precipitation shield expanded into the Ohio Valley.
 - The merger of the polar jet and subtropical jet at 1200 GMT 3 February appears to shift the axis of maximum wind speeds toward the base of the trough, concurrent with an increase of the geopotential gradients. The possible interaction of subtropical and polar jets at and after 1200 GMT 3 February yields a complex

jet pattern at 200 and 300 mb as two distinct regions of maximum wind speeds were observed downwind of the trough axis at separate levels and locations.

- The development of the secondary surface low after 0000 GMT 4 February appears to occur in the diffluent exit region of the jet streaks located near the base of the trough (especially at 1200 GMT 4 February).

o Other jet characteristics

- A 50 m s⁻¹ polar jet associated with the confluent region across the northeastern United States on 2 and 3 February 1961 coincided with the extension of the cold surface anticyclone from New England to the Middle Atlantic states.

500 MB HEIGHTS AND UPPER-LEVEL WINDS

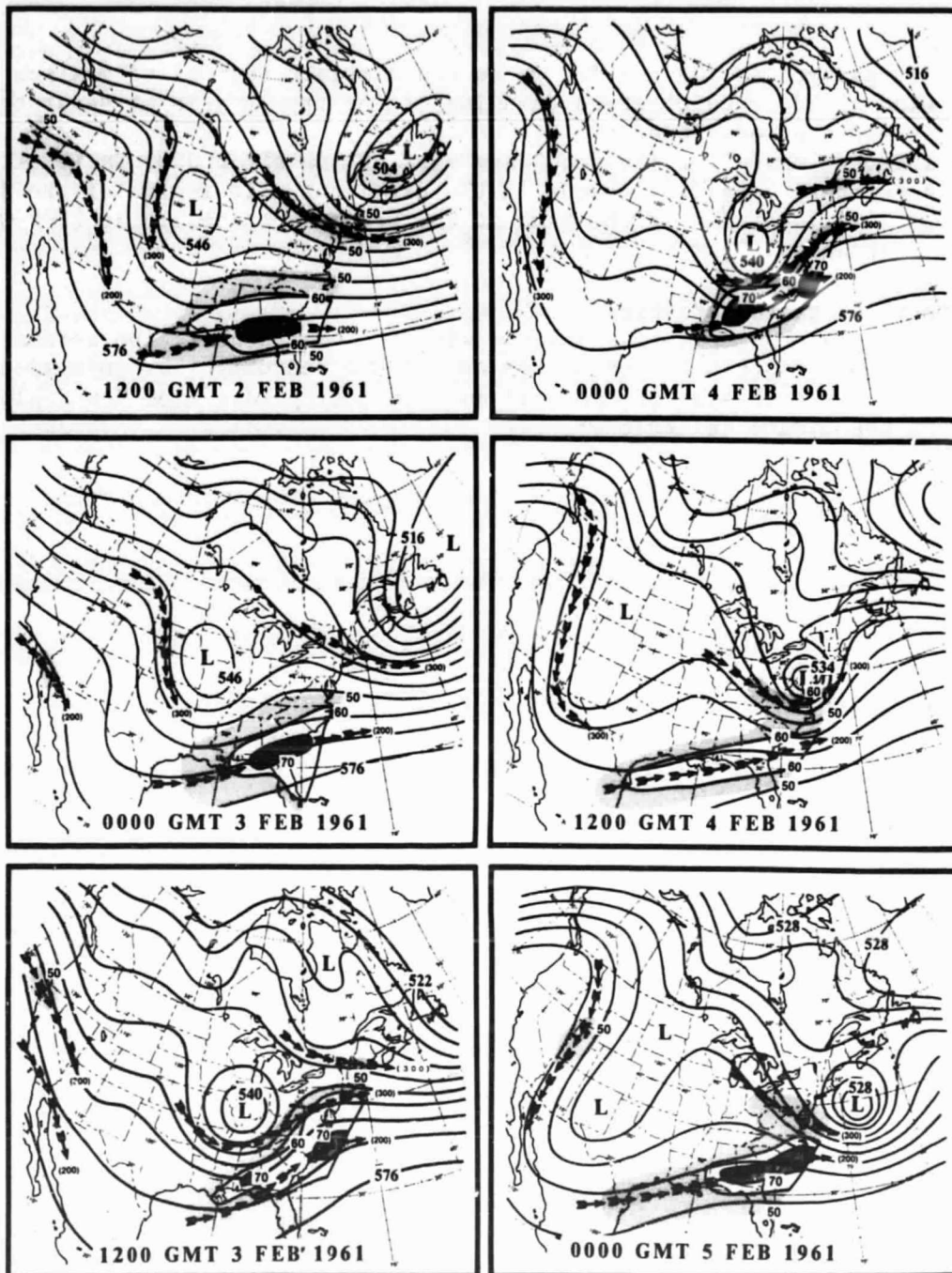


Fig. 16. The 500 mb geopotential height analyses and isotachs of maximum wind speeds for 1200 GMT 2 February, 0000 GMT 3 February, 1200 GMT 3 February, 0000 GMT 4 February, 1200 GMT 4 February, and 0000 GMT 5 February 1961. See Fig. 4 caption for details.

5-7 March 1962

2e. 5-7 MARCH 1962

o General Remarks

- The storm has been called the "Great Atlantic Coastal Storm" for the highly destructive tidal surges along the Middle Atlantic Coast which were set up by sustained high easterly winds and a long fetch over the ocean. Permanent changes to the coastline resulted from the storm.
- Heavy snowfall distribution was unusual with up to 42" (107 cm) falling in the mountains of Virginia. However, most urban centers in the Northeast corridor escaped heavy accumulations.

o Regions with snow accumulations exceeding 10 in (25 cm)

- southern and western Pennsylvania, portions of Maryland, central and northern Virginia, and West Virginia

o Regions with snow accumulations exceeding 20 in (51 cm)

- portions of southern Pennsylvania, eastern West Virginia, and western Virginia

o Urban center snowfall amounts:

Washington, D.C.-National Airport	4.0" (10 cm)
Baltimore, Md.	13.0" (33 cm)
Philadelphia, Pa.	6.8" (17 cm)
New York, N.Y.-La Guardia Airport	0.7" (2 cm)
Boston, Ma.	0.9" (2 cm)

o Other selected snowfall amounts:

Big Meadows, Va.	42.0" (107 cm)
Elkins, W.V.	18.2" (46 cm)
Pittsburgh, Pa.	15.7" (40 cm)
Richmond, Va.	15.2" (39 cm)

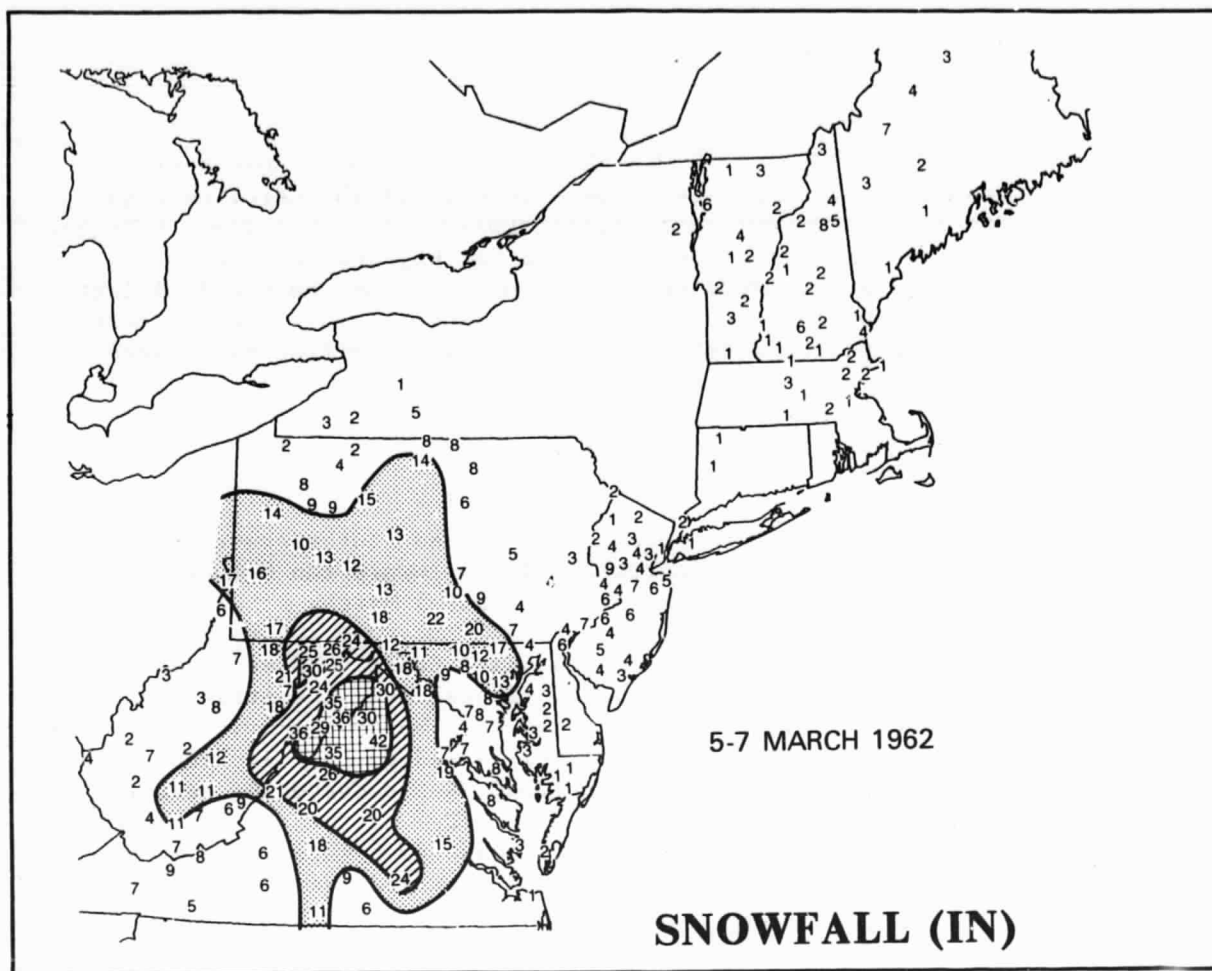


Fig. 17. Total snow accumulations for 5 to 7 March 1962 (in). See Fig. 1 caption for details.

Surface characteristics

- o Type "A" or "B" (Miller, 1946)
- o A large anticyclone (1064 mb) was located over northeastern Canada prior to sea-level development off the Carolina coast. Its ridge axis extended southeastward into New England bringing sub-freezing temperatures across New England and near or slightly-above freezing temperatures across the Middle Atlantic states. During the course of the storm period, the air mass over the northeastern United States was modified by a large easterly fetch over the Atlantic Ocean.
- o An ill-defined succession of low pressure centers characterized this storm.
- o Initial low pressure centers propagated southeastward and redeveloped from the northern Plains toward the Ohio Valley between 1200 GMT 4 March and 1200 GMT 5 March.
- o A low pressure center along the East Coast (NMC analyses indicate possibly more than one center over the Atlantic) developed off the Carolina coast on 5 March and drifted to near Norfolk, Va. late on 5 March and inland to near Richmond, Va. early on 6 March, where it filled. Rapid deepening occurred between 1200 GMT 5 March and 0600 GMT 6 March. A new center developed well off the Virginia coast on 6 March, and it also deepened rapidly as it propagated eastward over the ocean during the day.
- o Coastal frontogenesis was not analyzed, but may have been present off the Carolinas between 0000 GMT and 1200 GMT 5 March. There is also evidence of weak cold air damming from New England through the Middle Atlantic states on 5 March.
- o The interaction between the slow-moving anticyclone over Canada and the redeveloping coastal cyclogenesis created an intense and widespread pressure gradient that contributed to the strong easterly flow along the coast that persisted for several days.

SURFACE

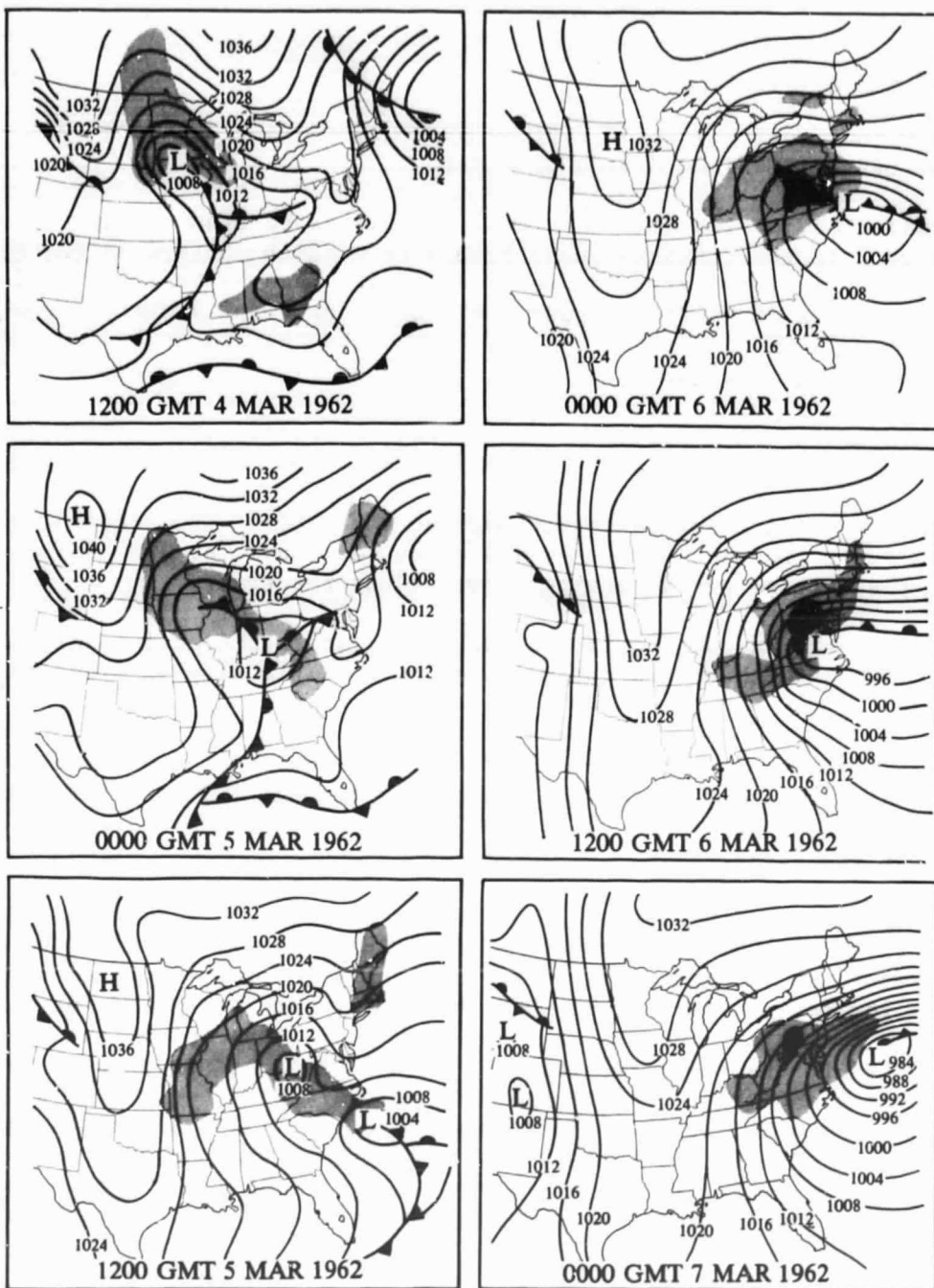


Fig. 18. Surface frontal and weather analyses for 1200 GMT 4 March, 0000 GMT 5 March, 1200 GMT 5 March, 0000 GMT 6 March, 1200 GMT 6 March, and 0000 GMT 7 March 1962. See Fig. 2 caption for details.

850 mb characteristics

- o No strong cold advection pattern preceded the storm across the northeastern United States on 4 March.
- o A major 850 mb low drifted slowly southeastward from the Upper Midwest to the Virginia coast from 4 to 6 March where a second center appeared to form eastward over the ocean. The 850 mb low filled slightly as it drifted across the Midwest on 4 and 5 March, deepened after 0000 GMT 6 March after it reached the East Coast and evolved into a large vortex.
- o The lack of a major cold outbreak prior to cyclogenesis along the East Coast is reflected by the weak temperature gradient along the East Coast. A cold pool of air at 850 mb was located consistently to the west of the low center throughout the study. The temperature gradients increased somewhat along the East Coast at 0000 GMT 6 March as the cyclone was deepening slowly along the coast.
- o The "S"-shaped pattern in the thermal field became well established by 0000 GMT 6 March as the surface low was intensifying along the coast.
- o The 0°C isotherm was initially displaced a considerable distance south and east of the 850 mb low center through 1200 GMT 5 March, but became oriented closer to the low center as cyclogenesis occurred along the coast.
- o Heavy snow in Pennsylvania, Maryland, Virginia and West Virginia occurred without the presence of a large low-level thermal gradient. However, an exceptionally intense easterly jet formed to the north of the low center starting at 0000 GMT 6 March and persisted for at least two days. The easterly jet formed as local height falls shifted to the coast and increased slightly in magnitude and was probably important for transporting moisture into the region of heavy snow in the Middle Atlantic states. Orography also appears to have played a significant role in the locations of the heaviest snow amounts in West Virginia and Virginia, in combination with the strong easterly flow in the lower troposphere.

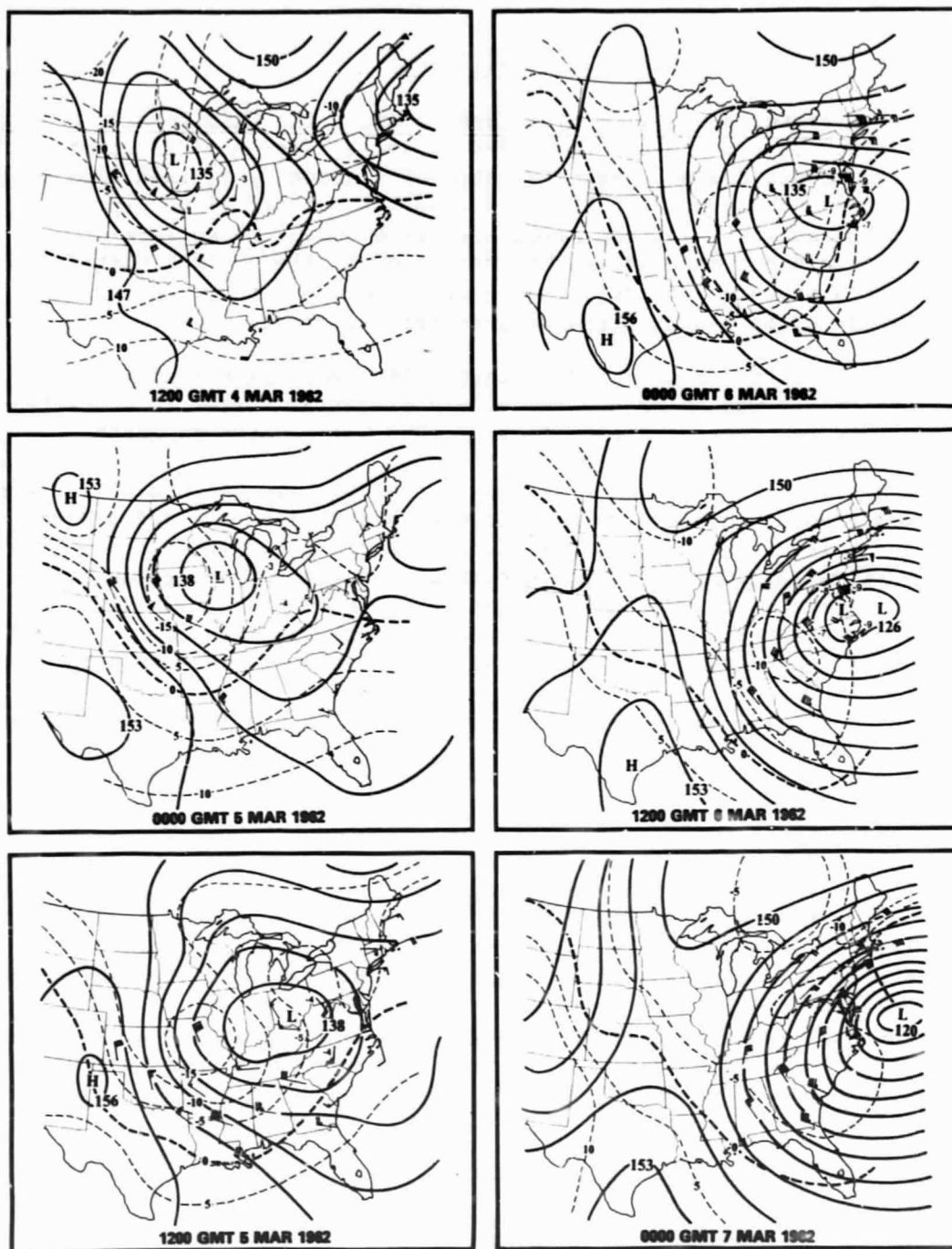


Fig. 19. The 850 mb analyses for 1200 GMT 4 March, 0000 GMT 5 March, 1200 GMT 5 March, 0000 GMT 6 March, 1200 GMT 6 March, and 0000 GMT 7 March 1962. See Fig. 3 caption for details.

500 mb geopotential height characteristics

- o General features prior to cyclogenesis along the East Coast
 - The 500 mb pattern was dominated by large, slow-moving cut-off troughs and ridges, characteristic of a strongly blocked flow over eastern Canada and the United States. A cut-off ridge over northeastern Canada was associated with a 1064 mb surface anticyclone, while an amplifying trough in the central United States appeared to "dig" southeastward and undercut the ridge in Canada as it slowly propagated toward the coast.
- o Characteristics of trough associated with East Coast cyclogenesis
 - The trough was an expanding, slowly deepening vortex that drifted slowly southeastward from Iowa at 1200 GMT 4 March to North Carolina by 0000 GMT 7 March.
 - The tilt of the trough axis became negative as the initial surface low pressure centers moved into the Ohio Valley on 4 and 5 March. The tilt of the major trough became less negatively tilted in the vertical by 6 March as surface redevelopment was occurring along the East Coast, but rotated sharply again by 0000 GMT 7 March in conjunction with the rapid deepening of the surface low.
 - Diffluence downwind of the trough axis was observed from 4 through 6 March.
 - Geopotential gradients at the base of the trough increased between 1200 GMT 4 March and 1200 GMT 6 March as the upper-level vortex moved southeastward from the Ohio Valley to the Carolina coast.
 - The amplitude of the trough and upstream ridge across the western United States increased significantly between 1200 GMT 4 March and 1200 GMT 5 March, prior to East Coast cyclogenesis [e.g., the latitudinal separation between trough and ridge axes (using the 5520 m contour) increased by 12° in the 48-h period ending at 1200 GMT 6 March]. The amplitude of the trough (when it reached the eastern United States) and downstream ridge off the East Coast increased to a lesser extent after 1200 GMT 5 March.
 - The half-wavelength of the trough and downstream ridge appears to have decreased only slightly after 1200 GMT 5 March as coastal cyclogenesis was occurring.

Upper-level jet characteristics

- o Jet streak characteristics of the cyclone-associated trough and flanking ridges
 - A subtropical jet with wind speeds in excess of 70 m s^{-1} was located over the southeastern United States prior to 1200 GMT 5 March in the downstream ridge prior to secondary cyclogenesis.
 - A polar jet at 300 mb with speeds in excess of 50 m s^{-1} at the crest of the upstream ridge at 1200 GMT 4 March plunged southeastward in the next 24 h into the base of the trough over the central United States. The polar jet appears to have interacted with the subtropical jet located further to the south.

Cyclogenesis at and after 1200 GMT 5 March appears to have occurred in the diffluent exit region of this complex jet system to the southeast of the slowly expanding upper-level vortex. However, since strongest winds remained over the Gulf of Mexico during cyclogenesis, in conjunction with the large geopotential gradients located there, the wind characteristics are difficult to determine.

500 MB HEIGHTS AND UPPER-LEVEL WINDS

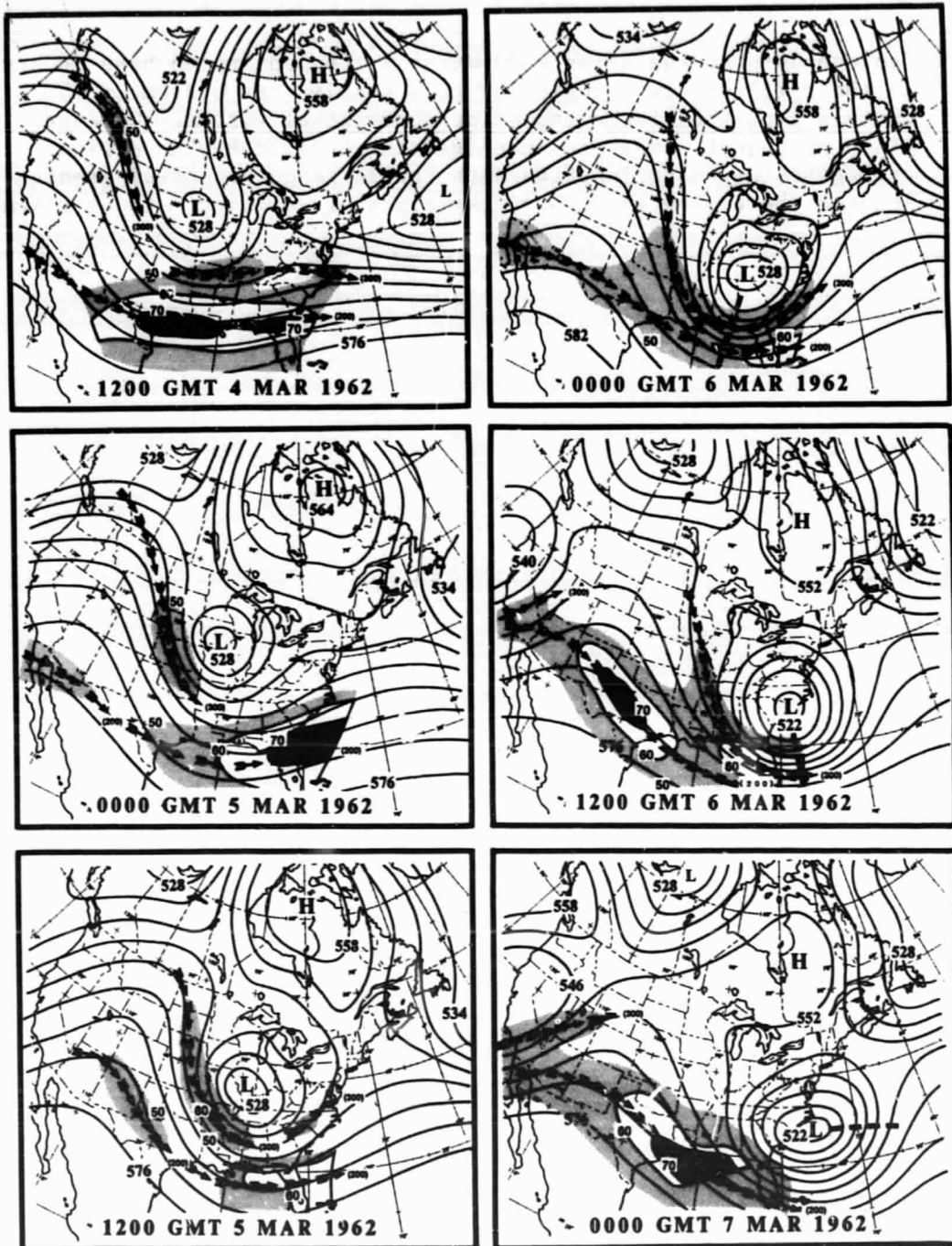


Fig. 20. The 500 mb geopotential height analyses and isotachs of maximum wind speeds for 1200 GMT 4 March, 0000 GMT 5 March, 1200 GMT 5 March, 0000 GMT 6 March, 1200 GMT 6 March, and 0000 GMT 7 March 1962. See Fig. 4 caption for details.

11-13 January 1964

2f. 11-13 JANUARY 1964

o General Remarks

- This case was a large, slow-moving storm that produced severe winter weather throughout the central and eastern United States. Blizzard conditions prevailed throughout the Middle Atlantic states and southern New England as temperatures fell below -7°C and wind speeds increased to greater than gale force.

o Regions with snow accumulations exceeding 10 in (25 cm)

- central and northern West Virginia, northern Maryland, the northern tip of Virginia, Pennsylvania (except the extreme northwest and southeast), New Jersey, the southeastern half of New York, portions of Connecticut and Massachusetts, Rhode Island, southern Vermont, New Hampshire and Maine

o Regions with snow accumulations exceeding 20 in (51 cm)

- portions of Pennsylvania and south-central New York

o Urban center snowfall amounts:

Washington, D.C.-Dulles Airport	10.2" (26 cm)
Washington, D.C.-National Airport	8.5" (22 cm)
Baltimore, Md.	9.9" (25 cm)
Philadelphia, Pa.	7.2" (18 cm)
New York, N.Y.-Central Park	12.5" (32 cm)
Boston, Ma.	9.2" (23 cm)

o Other selected snowfall amounts:

Williamsport, Pa.	24.1" (61 cm)
Scranton, Pa.	21.1" (54 cm)
Nantucket, Ma.	19.2" (49 cm)
Harrisburg, Pa.	18.1" (46 cm)
Pittsburgh, Pa.	15.6" (40 cm)
Hempstead, N.Y.	14.7" (37 cm)

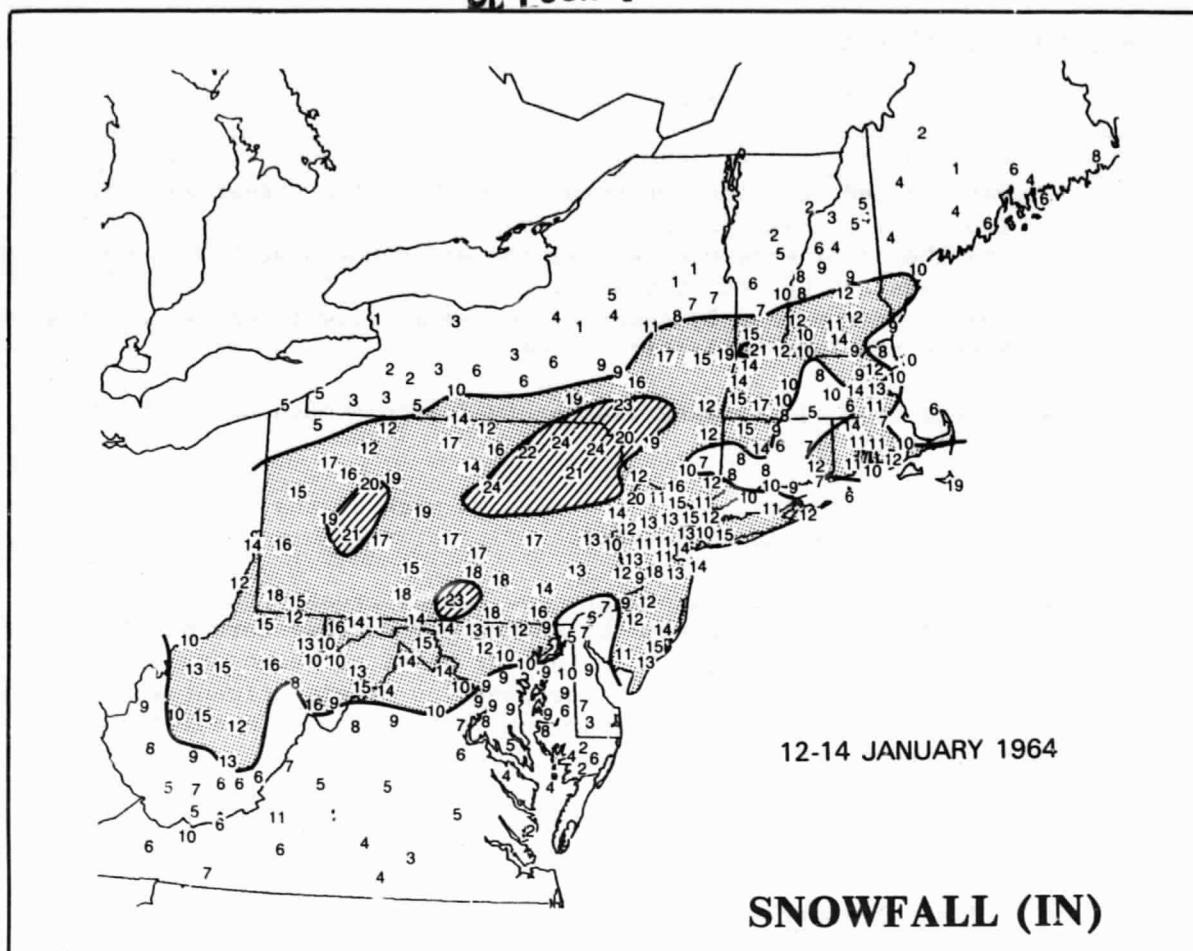


Fig. 21. Total snow accumulations for 12 to 14 January 1964 (in). See Fig. 1 caption for details.

Surface characteristics

- o Type "B" (Miller, 1946)
- o A large, intense anticyclone (1046 mb at 0000 GMT 12 January) was located near the Northern Plains-Canadian border and had two axes; one extending south from the Northern Plains to Texas, and the other extending across the Great Lakes states in the northeastern United States and then southward along the Atlantic Coast, accompanied by temperatures well below freezing into the Middle and South Atlantic states.
- o Strong cold air damming was observed across much of the East Coast on 12 January.
- o A large cyclonic circulation covered much of the eastern United States from 12 to 14 January.
- o A slowly intensifying primary low center crossed from Kansas to Tennessee to Kentucky before fading out over western Virginia by 1200 GMT 13 January, 24 h after the onset of secondary cyclogenesis. This low was accompanied by significant snowfall from Missouri and Iowa across the Ohio Valley to Pennsylvania with accumulations exceeding 25 cm.
- o The secondary cyclone developed as a series of weak lows over the southeastern United States slowly evolved into one low center off the Carolina coasts late on 12 January.
 - The secondary low developed on 1200 GMT 12 January along a developing coastal front with moderate-to-heavy precipitation forming to the west of the coastal front on the morning of 12 January.
 - The system had an erratic history of intensification. The low deepened rapidly after it first formed prior to 0000 GMT 13 January, then appeared not to deepen at all off the East Coast early on 13 January and then deepened rapidly again later on 13 January off the southern New England coast.
- o Both primary and secondary low centers moved at a relatively slow rate, averaging 9 to 12 m s⁻¹.

SURFACE

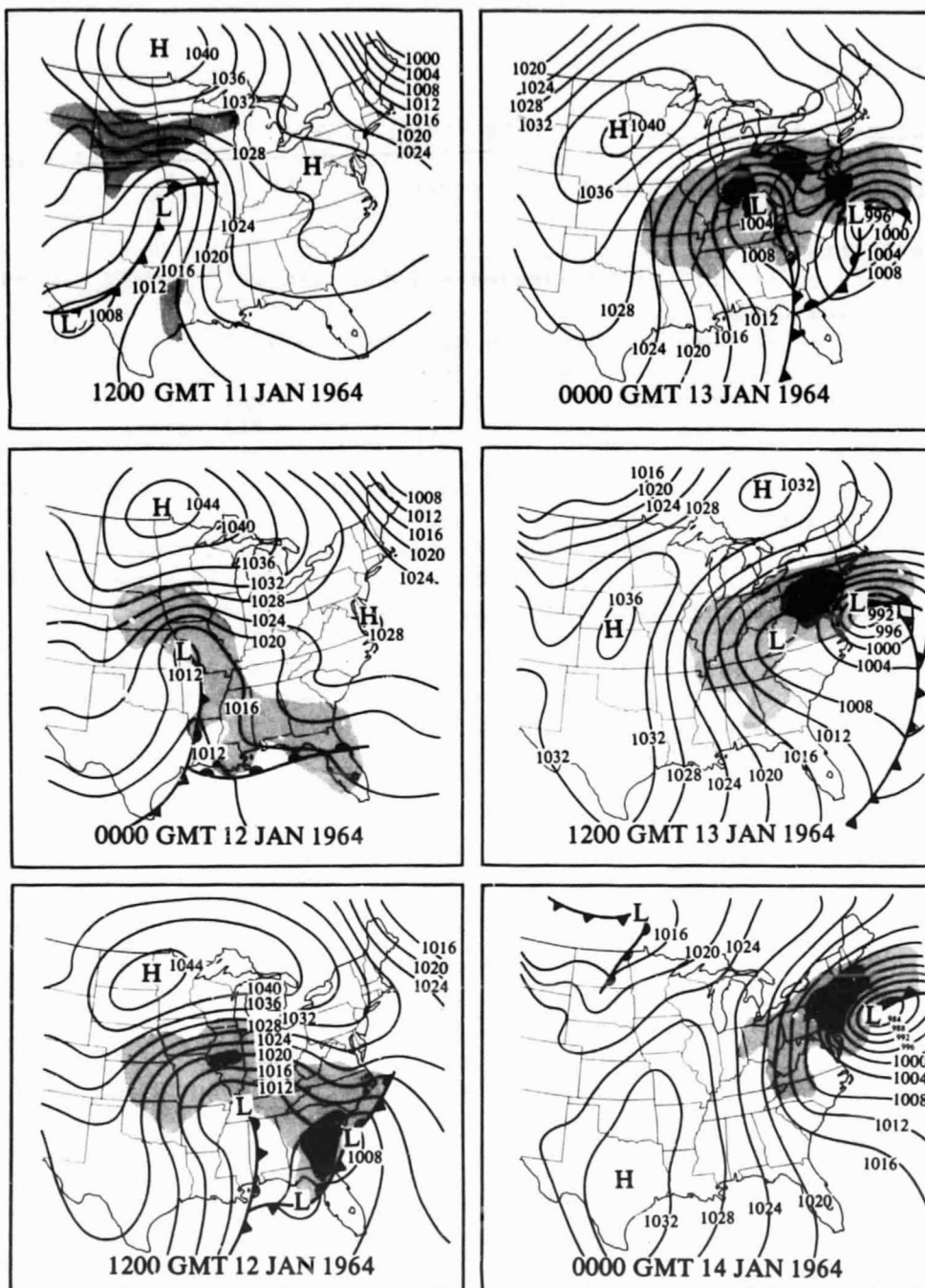


Fig. 22. Surface frontal and weather analyses for 1200 GMT 11 January, 0000 GMT 12 January, 1200 GMT 12 January, 0000 GMT 13 January, 1200 GMT 13 January, and 0000 GMT 14 January 1964. See Fig. 2 caption for details.

850 mb characteristics

- o Strong cold advection and northwesterly flow across the northeastern United States was located beneath a distinct region of upper-level confluence between 1200 GMT 11 January and 1200 GMT 12 January.
- o The initial 850 mb low center drifted eastward from Kansas to West Virginia on 11 through 13 January and deepened very slowly. A secondary 850 mb low center developed near the South Carolina-Georgia border at 1200 GMT 12 January and deepened at a more rapid pace than the primary low as it propagated northeastward along the East Coast, especially between 1200 GMT 13 January and 0000 GMT 14 January. During this period, the two low centers consolidated into one center along the coast.
- o The formation of a secondary 850 mb low center at 1200 GMT 12 January occurred with the development of a 20 m s⁻¹ south to southeasterly low-level jet, as coastal frontogenesis was occurring off the Southeast United States coast, and as moderate to heavy precipitation was developing across Georgia and South Carolina.
- o An "S"-shaped pattern in the thermal field was observed as early as 0000 GMT 12 January associated with the primary low pressure system and translated eastward in the following two days as secondary cyclogenesis occurred off the Atlantic coast.
- o The temperature gradient increased along the Middle Atlantic states at 1200 GMT 12 January and 0000 GMT 13 January with the onset of secondary cyclogenesis, coastal frontogenesis and the formation of the low-level jet.
- o The 0°C isotherm was generally displaced south and east of the initial 850 mb low and was displaced to the north of the secondary 850 mb center at 0000 GMT 13 January.
- o A strong easterly jet was noted to the north of both primary and secondary 850 mb low centers on 12, 13 and 14 January, but was most intense at 0000 GMT 14 January as the 850 mb low deepened rapidly.
- o The development of a coastal height fall center and low-level jet over a 12 h period ending at 1200 GMT 12 January 1964 occurred in a similar manner to that described for the February 1979 "Presidents' Day" storm (Bosart, 1981; Uccellini et al., 1983, 1984a), in which these features developed in a regime in which winds at the subtropical jet level increased, cold air was dammed along the Appalachian Mountains, and coastal frontogenesis and precipitation were occurring near the Southeast United States coast. The low-level jet and height fall centers formed at a considerable distance from the main 850 mb low center while the low-level jet increased lower-tropospheric thermal and moisture advections across the Middle Atlantic states. The January 1964 case differs from the 1979 case in that the 1964 cyclone was of a much larger scale, and the formation of a low-level jet occurred with a better-defined coastal height fall center than that diagnosed for the 1979 case.

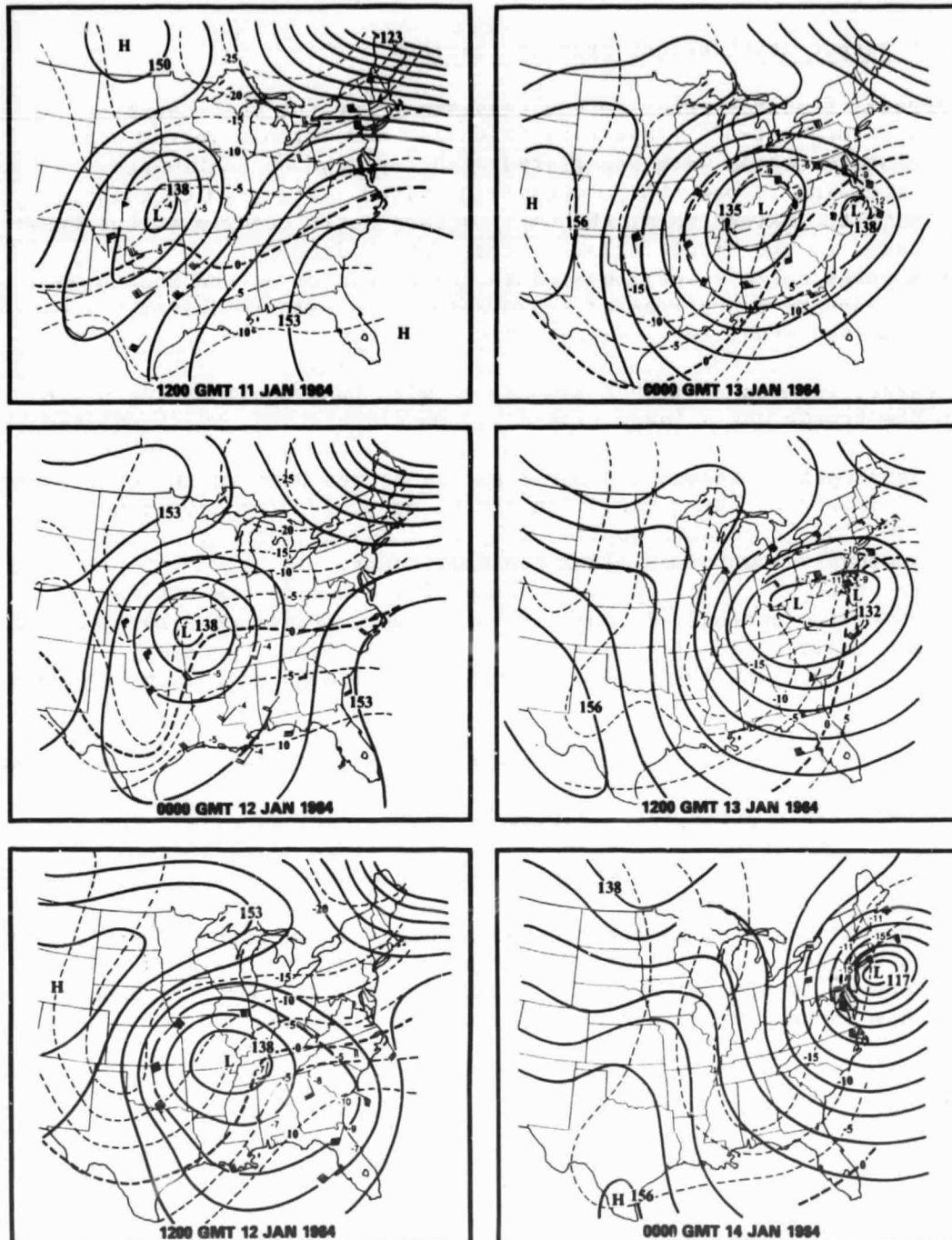


Fig. 23. The 850 mb analyses for 1200 GMT 11 January, 0000 GMT 12 January, 1200 GMT 12 January, 0000 GMT 13 January, 1200 GMT 13 January, and 0000 GMT 14 January 1964. See Fig. 3 caption for details.

500 mb geopotential height characteristics

- o General features prior to cyclogenesis along the East Coast
 - A strong cut-off ridge over Greenland and intense vortex over eastern Canada were associated with a region of confluence extending across the northeastern United States, which coincided with the extension of the cold surface anticyclone over the Great Lakes to the Middle Atlantic coast on 12 January.
 - A large cut-off low, located in the center of United States on 12 January downstream of ridge across the western United States, provided upper-level support for the storm.
- o Characteristics of trough associated with East Coast cyclogenesis
 - The trough was a large closed 500 mb circulation, which drifted across the central and eastern United States as the primary low developed in Kansas and moved slowly to the Ohio Valley on 11 and 12 January. The circulation center deepened from 5300 m at 1200 GMT 12 January to 5120 m by 0000 GMT 14 January as the secondary low formed along the East Coast.
 - The tilt of the trough axis was positive during the entire observing period, although it became more north-south by 13 January as the secondary low developed along the coast. However, diffluence was observed downwind of the trough axis from 12 January through 14 January.
 - The amplitude of the trough-ridge system, which spanned the entire United States, does not appear to increase significantly immediately prior to or during secondary cyclogenesis. The amplitude of the trough and downstream ridge along the East Coast and eastward into the Atlantic increased only slightly throughout the study period.
 - The half-wavelength between the trough and downstream ridge appears to decrease significantly over the eastern United States, especially between 1200 GMT 11 January and 0000 GMT 13 January, when secondary surface cyclogenesis was underway.

Upper-level jet characteristics

- o Jet streak characteristics of the cyclone-associated trough and flanking ridges
 - An intensifying subtropical jet with maximum winds exceeding 70 m s^{-1} at 200 mb was located over the southeastern United States between 1200 GMT 11 January and 0000 GMT 12 January.
 - A new 200 mb wind maximum appears to have developed by 1200 GMT 12 January over the Middle Atlantic states and northeastern United States. This jet amplified to greater than 80 m s^{-1} over New England by 0000 GMT 13 January. The development and amplification of this feature occurred at the crest of the downstream ridge as coastal frontogenesis, secondary cyclogenesis, and heavy precipitation were breaking out over the southeastern United

States. The amplification of the upper-level jet streak (and a low-level jet streak along the Southeast coast discussed in the 850 mb section) in conjunction with developing heavy precipitation in Georgia and South Carolina at 1200 GMT 12 January is similar to that discussed for the February 1979 Presidents' Day storm (Uccellini et al., 1984).

- A weaker polar jet (60 m s^{-1}) propagated into the base of the 500 mb trough by 0000 GMT 13 January, as the secondary East Coast cyclone was initiated. Missing wind reports at the base of the East Coast vortex at 0000 GMT and 1200 GMT 13 January indicate that very high winds developed within this jet streak as it propagated toward the Middle Atlantic coastline with secondary cyclogenesis in progress off the East Coast.
 - The secondary low developed in the diffluent exit region of the complex jet system just east of the trough axis and in the entrance region of the confluent jet over New England (both jet quadrants favor ascent; see Part 1).
- o Other jet characteristics
- Missing wind reports across the northeastern United States at 1200 GMT 11 January and 0000 GMT 12 January are indicative of strong winds associated with a highly confluent polar jet during a period when cold, high sea-level pressure began to surge into the northeastern United States before cold air damming occurred in the Middle Atlantic region east of the Appalachian Mountains.

500 MB HEIGHTS AND UPPER-LEVEL WINDS

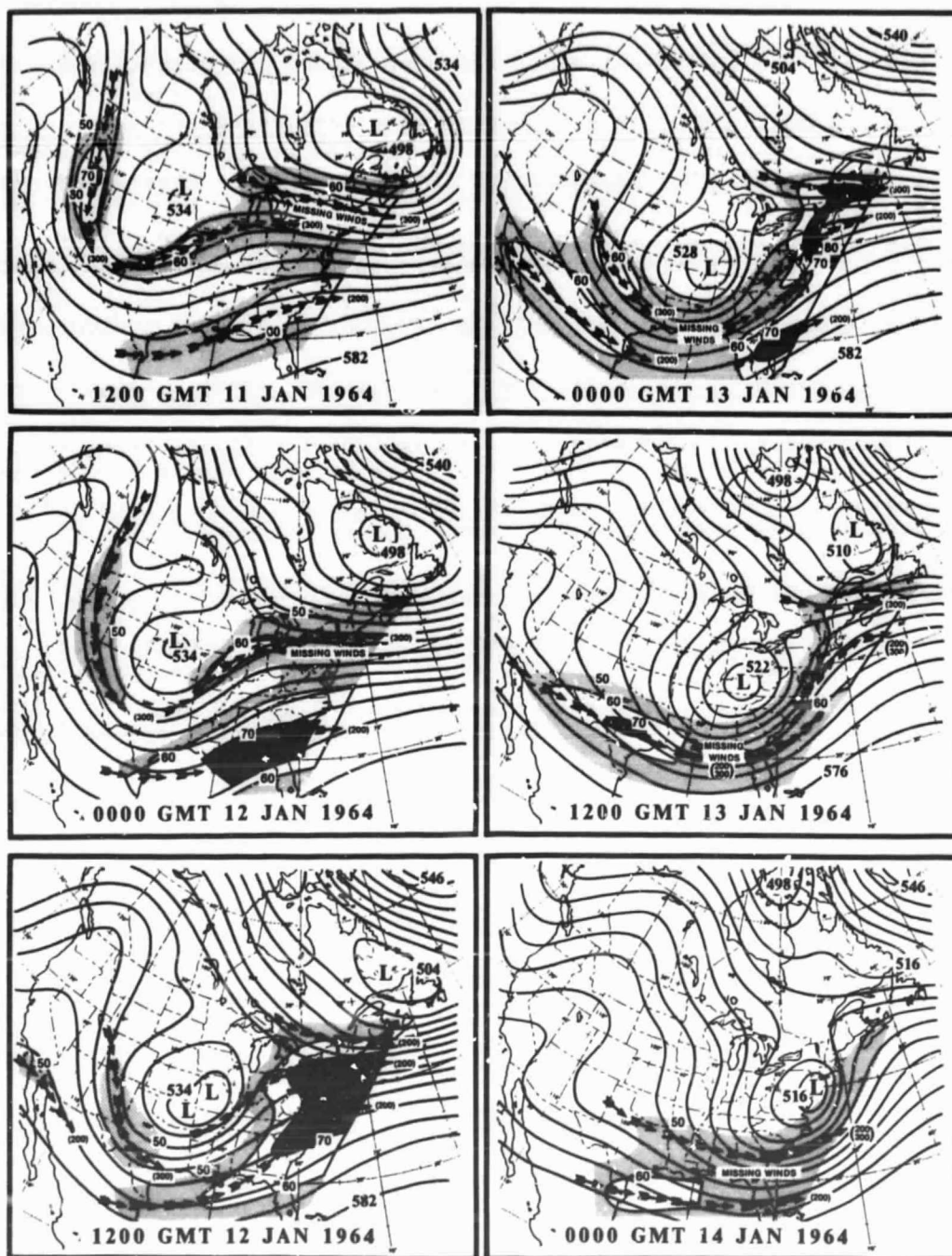


Fig. 24. The 500 mb geopotential height analyses and isotachs of maximum wind speeds for 1200 GMT 11 January, 0000 GMT 12 January, 1200 GMT 12 January, 0000 GMT 13 January, 1200 GMT 13 January, and 0000 GMT 14 January 1964. See Fig. 4 caption for details.

29-31 January 1966

2g. 29-31 JANUARY 1966

o General Remarks

- This storm is known as the "Blizzard of '66." The storm was the third and worst in a series of three snowstorms over a 10-day period along the Middle Atlantic Coast. Heavy snow fell from North Carolina north to New York and combined with temperatures below -10°C and wind gusts in excess of 25 m s^{-1} . Cyclone snowfall combined with "lake effect" snow across New York State to produce record accumulations of 150 to 250 cm immediately south and east of Lake Ontario. The axis of heaviest snowfall was oriented from southwest to northeast south of Virginia, but became aligned from north to south north of Virginia, and was displaced west of the immediate coast from New Jersey to New England, sparing the major metropolitan areas from Philadelphia to much of New England the storm's worst effects.

o Regions with snow accumulations exceeding 10 in (25 cm)

- parts of North Carolina, Virginia, West Virginia, Maryland, Delaware, northwestern New Jersey, central and eastern Pennsylvania, New York (except the northeast, southeast, and parts of the southwest) and scattered locations throughout New England

o Regions with snow accumulations exceeding 20 in (51 cm)

- central New York

o Urban center snowfall amounts:

Washington, D.C.-National Airport	13.8" (35 cm)
Baltimore, Md.	12.1" (31 cm)
Philadelphia, Pa.	8.3" (21 cm)
New York, N.Y.-Central Park	6.8" (17 cm)
Boston, Ma.	6.3" (16 cm)

o Selected snowfall amounts:

Syracuse, N.Y.	39.0" (99 cm) through January 31
Rochester, N.Y.	26.7" (68 cm) through January 31
Binghamton, N.Y.	20.1" (51 cm) through January 31
Roanoke, Va.	12.3" (31 cm)
Harrisburg, Pa.	12.2" (31 cm)

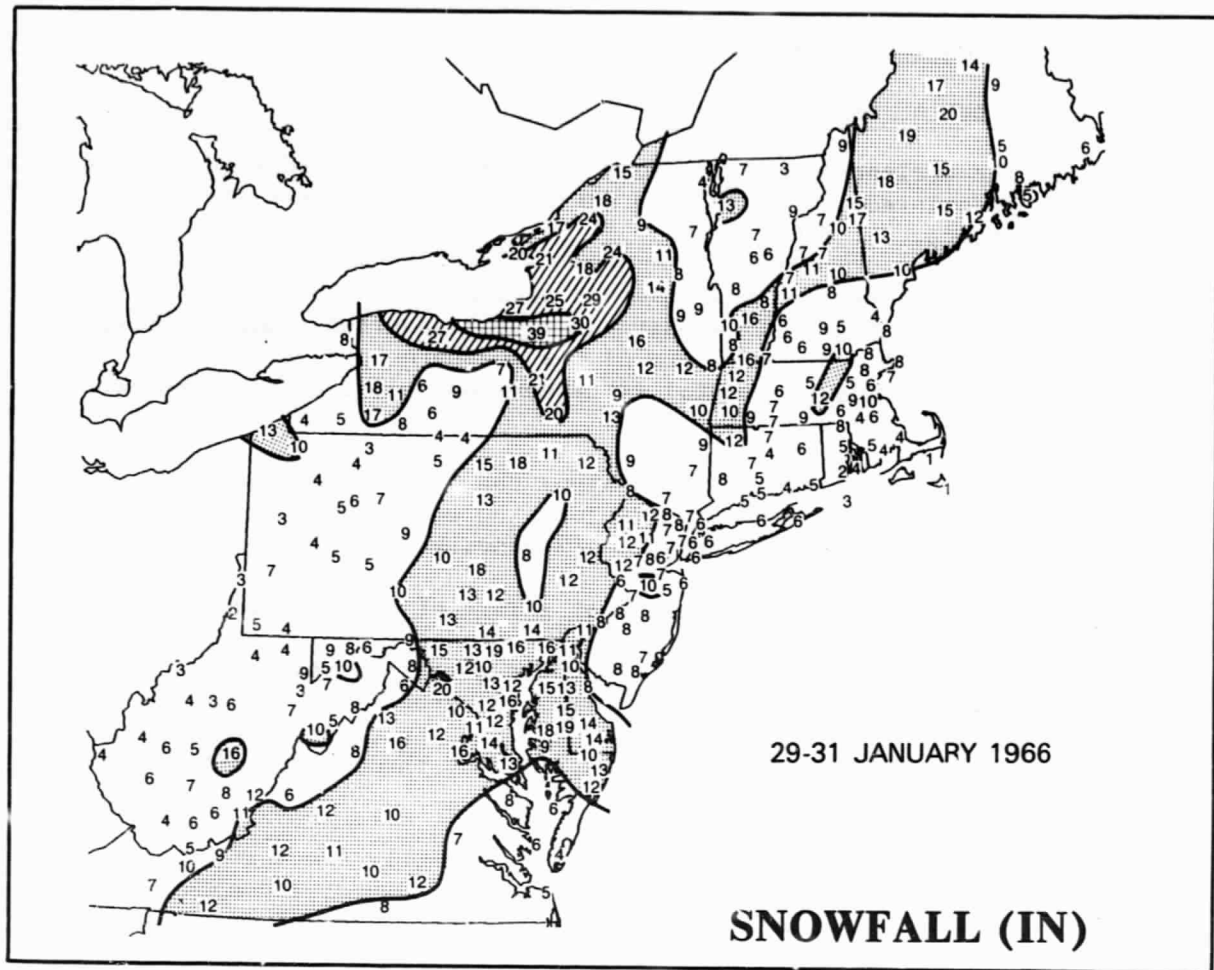


Fig. 25. Total snow accumulations for 29 to 31 January 1966 (in). See Fig. 1 caption for details.

Surface characteristics

- o Type "A" (Miller, 1946).
- o The cyclone developed along the edge of a record cold air mass associated with a 1055 mb anticyclone located over northern Canada.
- o Cold air damming was observed across the southeastern United States early on 29 January as a weak inverted trough developed along the western slopes of the southern Appalachians. Concurrently, a coastal front developed just off the Southeast United States coast.
- o The storm initially moved along the Gulf Coast before propagating northeastward along the developing coastal front near the Southeast coast on 29 January.
- o The surface low propagated at a rate of approximately 15 m s^{-1} along the Gulf Coast. It then had a tendency to jump or redevelop northeastward along the coastal front off the Southeast Coast late on 29 January, propagating at 25 m s^{-1} before reaching North Carolina. The low then deepened slowly as it propagated along the coastal front through the afternoon of 29 January.
- o The surface low then took a more northerly track after passing east of Cape Hatteras, N.C. late on 29 January, deepening explosively from 0000 GMT 30 January to 1800 GMT 30 January as the central pressure fell from 997 to 970 mb. Very heavy snowfall from Virginia to New York accompanied this stage of rapid development.
- o The subsequent track of the storm took it inland across extreme eastern New Jersey, New York City, and into western New England and eastern New York. Due to this northerly track, temperatures across much of the Middle Atlantic states never rose much above -10°C , where surface winds from the north-northwest increased during the day on 30 January. A wedge of drier and warmer air near and to the east of the low center raced up the coast where temperatures approached 5°C in New York City and southern New England, cutting down snowfall accumulations in those regions as snowfall ceased for a 6 to 9 h period.
- o Intense sea-level pressure gradients formed to the west and north of the low center, creating prolonged high wind conditions long after the low pressure system had passed.

SURFACE

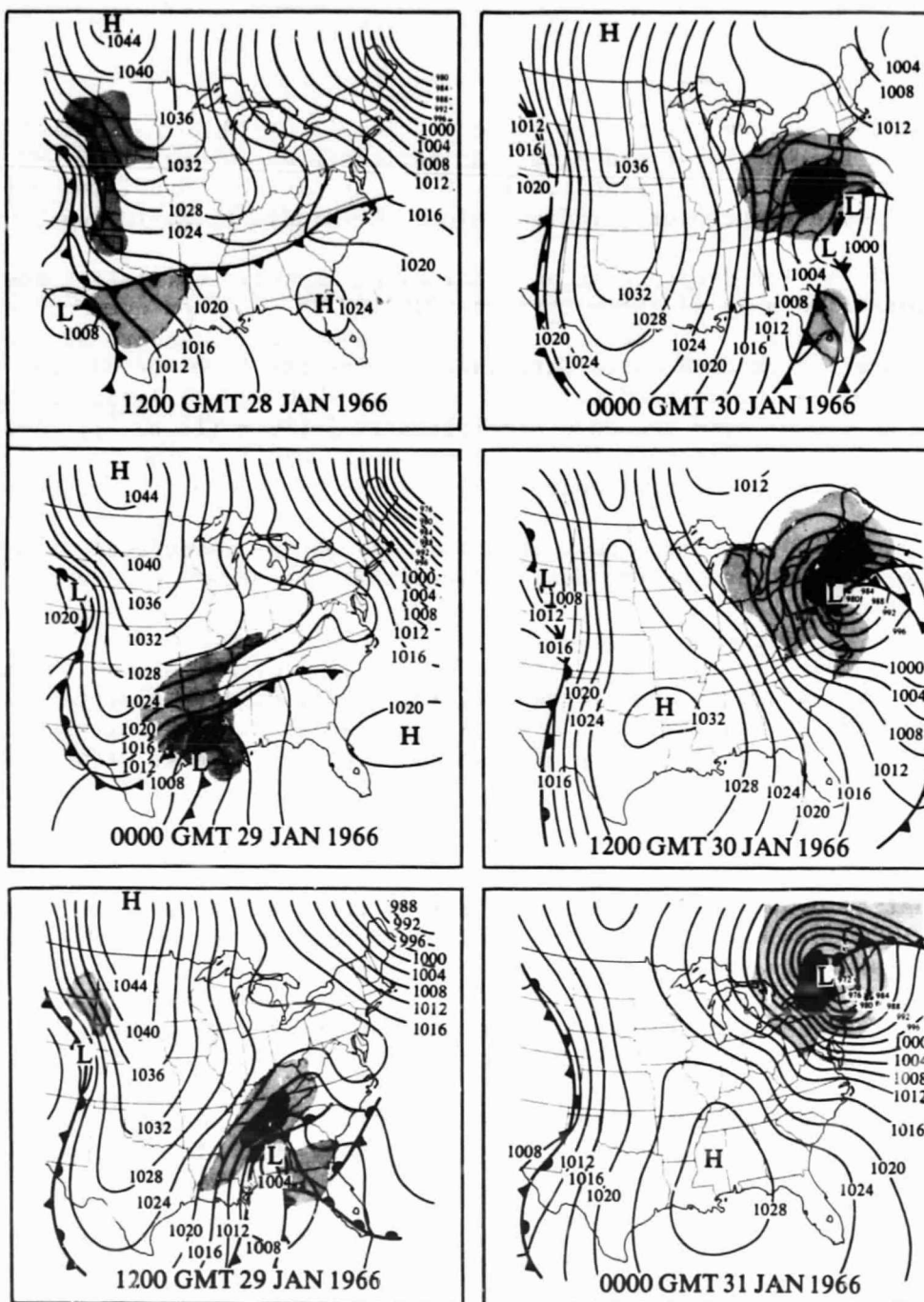
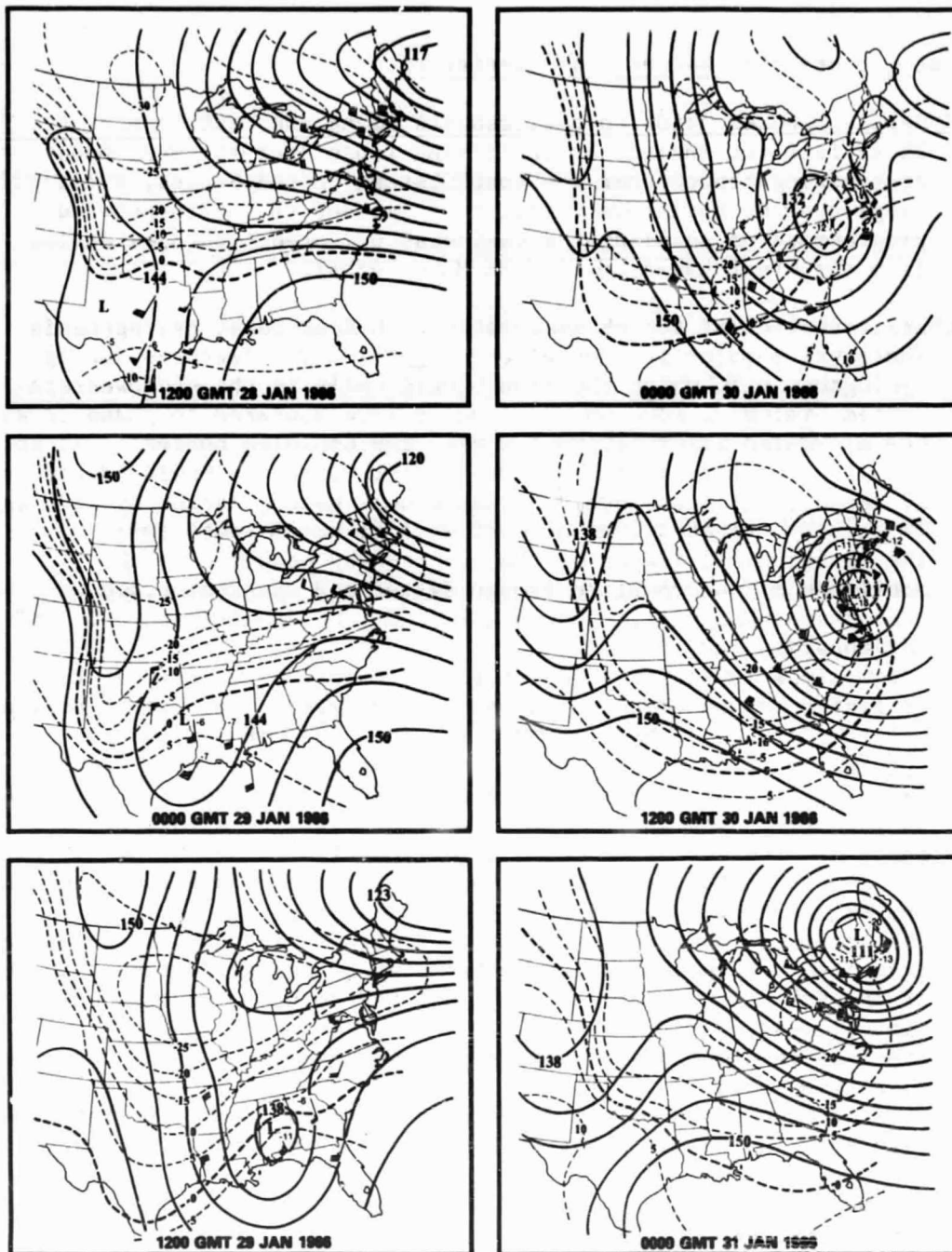


Fig. 26. Surface frontal and weather analyses for 1200 GMT 28 January, 0000 GMT 29 January, 1200 GMT 29 January, 0000 GMT 30 January, 1200 GMT 30 January, and 0000 GMT 31 January 1966. See Fig. 2 caption for details.

850 mb characteristics

- o A strong northwesterly flow of very cold air ($<-20^{\circ}\text{C}$) was maintained across the Northeast and Middle Atlantic states through 1200 GMT 29 January by a confluent low-level height pattern associated with a pronounced temperature gradient along the Middle Atlantic coast.
- o The 850 mb low deepened in an accelerated manner. Initially, the low intensified only slightly through 0000 GMT 29 and then deepened at a moderate rate [$-60 \text{ m (12 h)}^{-1}$] through 0000 GMT 30 January as the surface low reached North Carolina. During the 12 h period that the surface low intensified rapidly ending at 1200 GMT 30 January, the 850 mb center also deepened significantly [$-150 \text{ m (12 h)}^{-1}$]. A slower rate of intensification followed [$-60 \text{ m (12 h)}^{-1}$] in the 12 h period ending at 0000 GMT 31 January.
- o Only one low or height fall center at 850 mb was associated with this case, in contrast to the dual centers that characterized several type "B" storms.
- o The cyclone developed along the southern edge of an intense thermal zone that extended from the Southern Plains to the Middle Atlantic coast. This gradient became oriented on a north-south axis during rapid cyclogenesis on 30 January and was particularly intense with a 24°C difference in temperature between Washington, D.C. (-24°C) and New York City (0°C) at 1200 GMT 30 January.
- o A significant warm advection pattern developed along the Middle Atlantic coast by 0000 GMT 30 January and across the northeastern United States at 1200 GMT 30 January as the winds increased and crossed the isotherms at a significant angle.
- o An "S"-shaped temperature pattern did not truly develop until 1200 GMT 30 January during the explosive cyclogenesis.
- o The 0°C isotherm was oriented near the 850 mb low center except during the occluding stage of the cyclone when the low center was located in colder air over New England late on 30 January.
- o A southerly 10 to 20 m s^{-1} low-level jet in advance of the low was directed towards regions of precipitation during the early stages of cyclogenesis along the Gulf Coast. Little easterly flow to the north of the 850 mb low center was observed until rapid cyclogenesis occurred on the Atlantic coast at 1200 GMT 30 January. A very strong southeasterly jet located to the northeast of the 850 mb low developed after 0000 GMT 30 January, in association with rapid 850 mb deepening accompanied by 30 to 40 m s^{-1} speeds along the southern New England coast. This strong low-level flow was directed toward the regions reporting heavy snowfall, indicating that vertical motions and moisture transport associated with the low-level jet were significant for this case. A strong westerly jet to the rear of the cyclone developed by 0000 GMT 30 January, accompanied by wind speeds of 30 to 35 m s^{-1} , and persisted for at least 24 h .

850 MB



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Fig. 27. The 850 mb analyses for 1200 GMT 28 January, 0000 GMT 29 January, 1200 GMT 29 January, 0000 GMT 30 January, 1200 GMT 30 January, and 0000 GMT 31 January 1966. See Fig. 3 caption for details.

500 mb geopotential height characteristics

- o General features prior to cyclogenesis along the East Coast
 - These features include an amplifying ridge over the West Coast, a propagating trough over the southwestern United States, a cut-off ridge over northeastern Canada that impeded the northeastward progression of an elongated east-west oriented trough extending from the Great Lakes to off the Maine coast.
- o Characteristics of trough associated with East Coast cyclogenesis
 - There was a major reorientation of upper-level features during cyclogenesis in which the trough originally in the southwestern United States on 1200 GMT 28 January 1966 appeared to phase in with the elongated east-west vortex near the Canadian border as it split into two separate vortices. One center moved off Newfoundland on 29 January while the other, located near Lake Superior by 1200 GMT 29 January, rotated from an east-west to north-south axis.
 - The rotation and merger of the two troughs occurred as the amplitude of the combined trough system and upstream ridge increased substantially between 1200 GMT 28 January and 0000 GMT 30 January.
 - The maximum intensification of the surface low occurred as the diffluent region downwind of the trough axis became better defined off the East Coast between 0000 GMT and 1200 GMT 30 January.
 - The 500 mb vortex over eastern United States attained a highly negative tilt by 1200 GMT 30 January as the surface low continued to intensify even as it moved over the mountains of western New England. The vortex deepened significantly in the following 12 h.
 - The geopotential gradients at the base of the trough increased in the 24 h period ending at 1200 GMT 30 January.
 - The amplitude of the trough over the Ohio Valley and the downstream ridge over the northeastern United States increased after 1200 GMT 29 January as the surface low propagated to the Southeast United States Coast.
 - The half-wavelength of trough and downstream ridge also decreased greatly between 0000 GMT 29 January and 0000 GMT 30 January as the surface low developed along the East Coast and heavy precipitation developed in the southeastern and east-central United States.

Upper-level jet characteristics

- o Jet streak characteristics of the cyclone-associated trough and flanking ridges
 - As the 500 mb West Coast ridge amplified and as the upper Great Lakes 500 mb vortex began to rotate to a north-south axis on 28 and 29 January, a polar jet streak (50 m s^{-1}) propagated southeastward from the Northern Plains to the Gulf of Mexico between 1200 GMT 28 January and 1200 GMT 29 January.
 - A subtropical jet at 200 mb extending across the southeastern United States intensified and expanded in coverage between 1200 GMT

28 and 29 January during the early stages of cyclogenesis. The jet amplification also occurred as the coastal front developed along the Southeast coast and as precipitation expanded across the Gulf Coast region. Wind speeds increased from 70 to over 80 m s⁻¹ over the southeastern United States by 1200 GMT 29 January.

- The most remarkable wind feature was the apparent development of an 80 m s⁻¹ jet streak at 300 mb across the Middle Atlantic and New England states by 1200 GMT 29 January. The jet developed at the crest of the downstream ridge immediately prior to rapid cyclogenesis on the East Coast, and before the heavy snowfall enveloped the Middle Atlantic region by 0000 GMT 30 January.
- The strongest upper-level winds were consistently located downstream of the major trough throughout the study period, but winds increased at the base of the trough by 1200 GMT 30 January as the upper-level trough intensified and developed a negative tilt.

o Other jet characteristics

- A 60 m s⁻¹ polar jet over the northeastern United States was associated with the outbreak of cold air across the Eastern states prior to cyclogenesis and was located immediately south of the elongated 500 mb vortex on 28 January.

The figure consists of six maps of the North Pacific region, arranged in a 3x2 grid, showing the development of a low-pressure system from January 28 to 31, 1966. Each map displays pressure contours, high (H) and low (L) pressure centers, and wind vectors. The maps are labeled with their respective times:

- Top Left: 1200 GMT 28 JAN 1966. Shows a low-pressure center (L) at 504 mb and a high-pressure center (H) at 540 mb. Contours range from 50 to 564 mb.
- Top Right: 0000 GMT 30 JAN 1966. The low-pressure center has intensified to 510 mb. The high-pressure center is at 540 mb. Contours range from 50 to 576 mb.
- Middle Left: 0000 GMT 29 JAN 1966. The low-pressure center is at 510 mb. The high-pressure center is at 528 mb. Contours range from 50 to 576 mb.
- Middle Right: 1200 GMT 30 JAN 1966. The low-pressure center has intensified to 510 mb. The high-pressure center is at 534 mb. Contours range from 50 to 576 mb.
- Bottom Left: 1200 GMT 29 JAN 1966. The low-pressure center is at 516 mb. The high-pressure center is at 540 mb. Contours range from 50 to 576 mb.
- Bottom Right: 0000 GMT 31 JAN 1966. The low-pressure center has reached its minimum value of 498 mb. The high-pressure center is at 540 mb. Contours range from 50 to 576 mb.

76

23-25 December 1966

2h. 23-25 DECEMBER 1966

o General Remarks

- This case was a Christmas Eve snowstorm with widespread snow from the Southern Plains to New England. A notable aspect of the storm was numerous reports of thunderstorms and heavy snow from the Middle Atlantic states to New England. Snow amounts along coastal regions were reduced by sleet during the afternoon of the 24th.

o Regions with snow accumulations exceeding 10 in (25 cm)

- portions of central and northern Virginia, parts of Maryland and West Virginia, northern Delaware, eastern Pennsylvania, western New Jersey, eastern New York, western New England

o Regions with snow accumulations exceeding 20 in (51 cm)

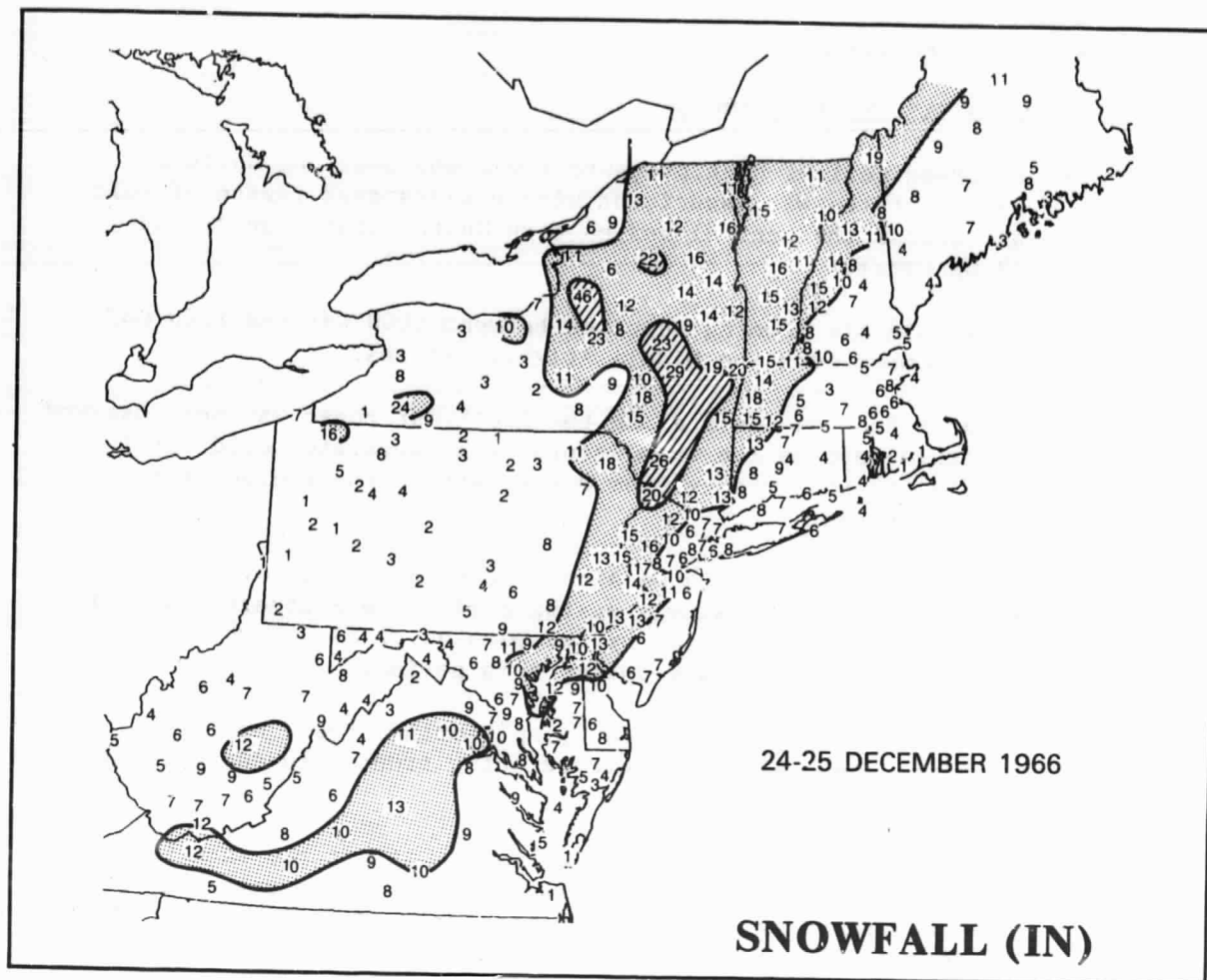
- parts of eastern New York

o Urban center snowfall amounts:

Washington, D.C.-Dulles Airport	9.2" (23 cm)
Baltimore, Md.	8.5" (22 cm)
Philadelphia, Pa.	12.7" (32 cm)
New York, N.Y.-Central Park	7.1" (18 cm)
Boston, Ma.	5.7" (14 cm)

o Other selected snowfall amounts:

Albany, N.Y.	18.7" (47 cm)
Burlington, Vt.	14.9" (38 cm)
Allentown, Pa.	13.3" (34 cm)
Wilmington, De.	12.5" (32 cm)
Trenton, N.J.	11.7" (30 cm)



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Fig. 29. Total snow accumulations for 24 to 25 December 1966 (in).
See Fig. 1 caption for details.

Surface characteristics

- o Type "A" (Miller, 1946)
- o A strong cell of high pressure (1042 mb) over the Northern Plains states was associated with a widespread region of cold air across the central and eastern United States on 22 and 23 December.
- o Weak cold air damming occurred between 0000 GMT and 1200 GMT 24 December over the Middle Atlantic states.
- o Coastal frontogenesis along the Southeast coast was not observed for this case as the main frontal zone separated cold air in the Middle Atlantic states from warmer air in the southeastern United States.
- o The surface low developed along the edge of the cold air outbreak and moved slowly eastward from the Southern Plains to the South Carolina coast by the morning of 24 December. The cyclone deepened slowly during this period.
- o The surface low appeared to "jump" northeastward near the Carolina coast along the pre-existing frontal boundary early on 24 December.
- o The cyclone then moved northeastward just off the East Coast during the 24 h period following 1200 GMT 24 December and deepened rapidly. Its central pressure had decreased by 22 mb in 24 h to 978 mb by the time it was located along the Maine coast at 1200 GMT 25 December.
- o The storm moved at a fairly even pace of $10 \text{ to } 15 \text{ m s}^{-1}$ as it moved up the East Coast, slowing as it neared New England.

SURFACE

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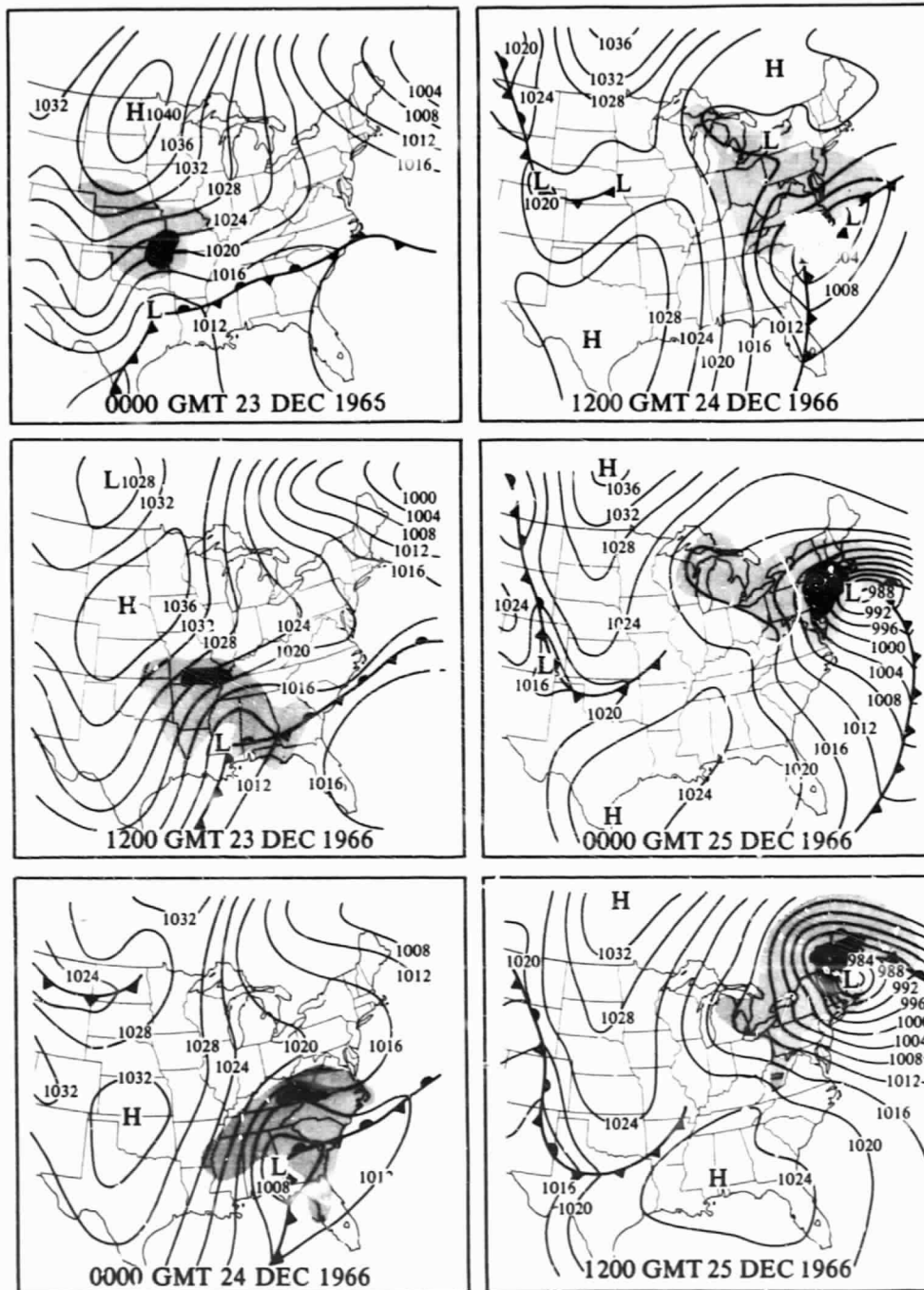


Fig. 30. Surface frontal and weather analyses for 0000 GMT 23 December, 1200 GMT 23 December, 0000 GMT 24 December, 1200 GMT 24 December, 0000 GMT 25 December, and 1200 GMT 25 December 1966. See Fig. 2 caption for details.

850 mb characteristics

- o West to northwesterly flow maintained cold air through 24 December in the northeastern United States.
- o The 850 mb low center deepened only slightly as it moved across the southeastern United States on 23 December, but it began to deepen more rapidly after 0000 GMT 24 December as it neared the East Coast.
- o The 850 mb low propagated along the edge of a narrow, but intense east-west aligned temperature gradient that evolved into an "S"-shaped pattern between 0000 and 1200 GMT 24 December.
- o The 0°C isotherm cut across the 850 mb low center until the cyclone occluded over New England by 1200 GMT 25 December, when the low center was located in colder air.
- o A strong northerly jet to the rear of the 850 mb low dominated early cyclogenesis across the southern United States on 23 December. Otherwise, weak flow was observed near the low center prior to 24 December. Wind speeds near the low center increased by 1200 GMT 24 December as the low neared the East Coast. The increased wind speed occurred to the south and east of the low as the surface cyclone was beginning a 24 h period of rapid cyclogenesis. Easterly flow to the north of the low increased by 0000 GMT 25 December during rapid 850 mb intensification as height gradients surrounding the low center intensified and was directed toward the area of heavy snowfall.

850 MB

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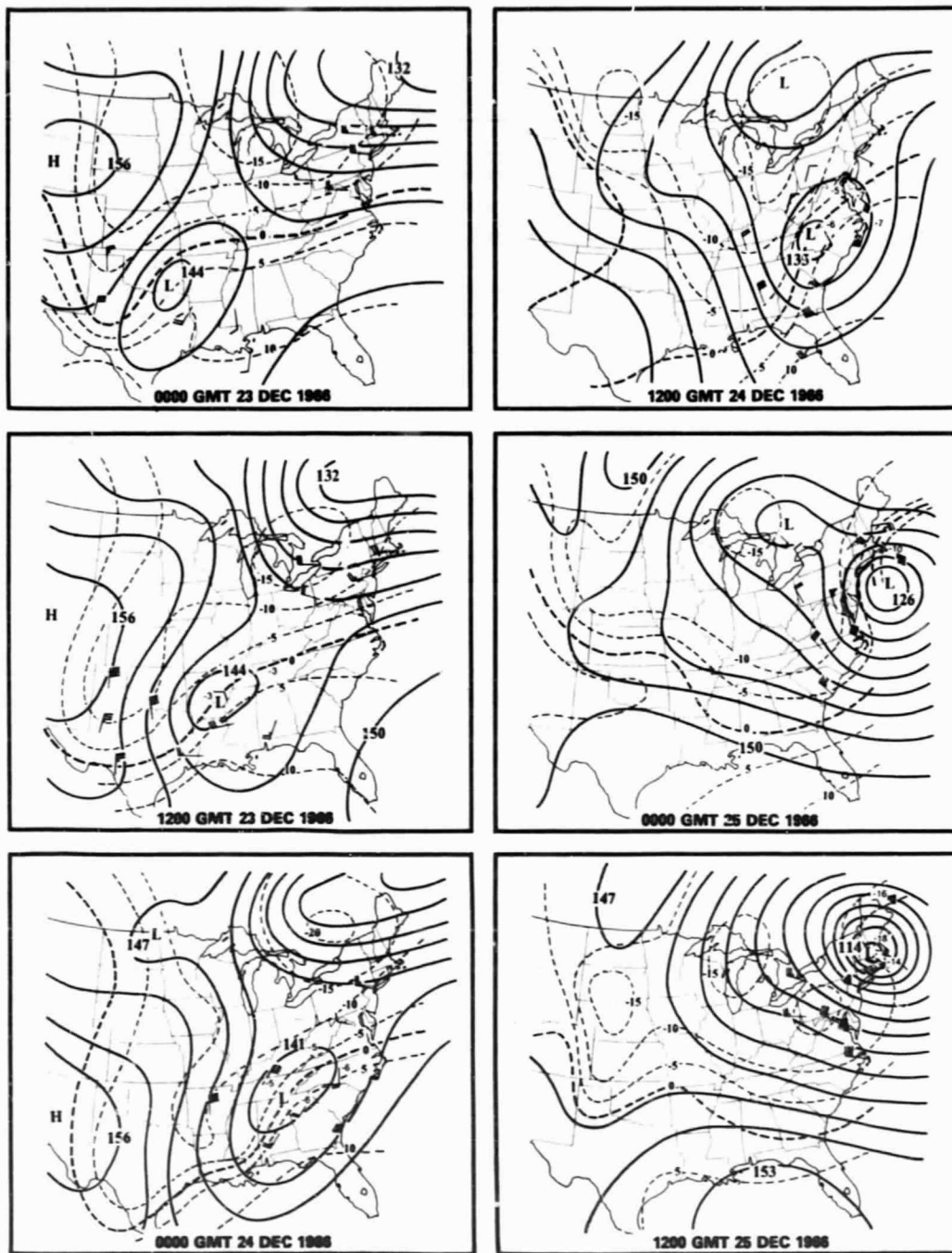


Fig. 31. The 850 mb analyses for 0000 GMT 23 December, 1200 GMT 23 December, 0000 GMT 24 December, 1200 GMT 24 December, 0000 GMT 25 December, and 1200 GMT 25 December 1966. See Fig. 3 caption for details.

500 mb geopotential height characteristics

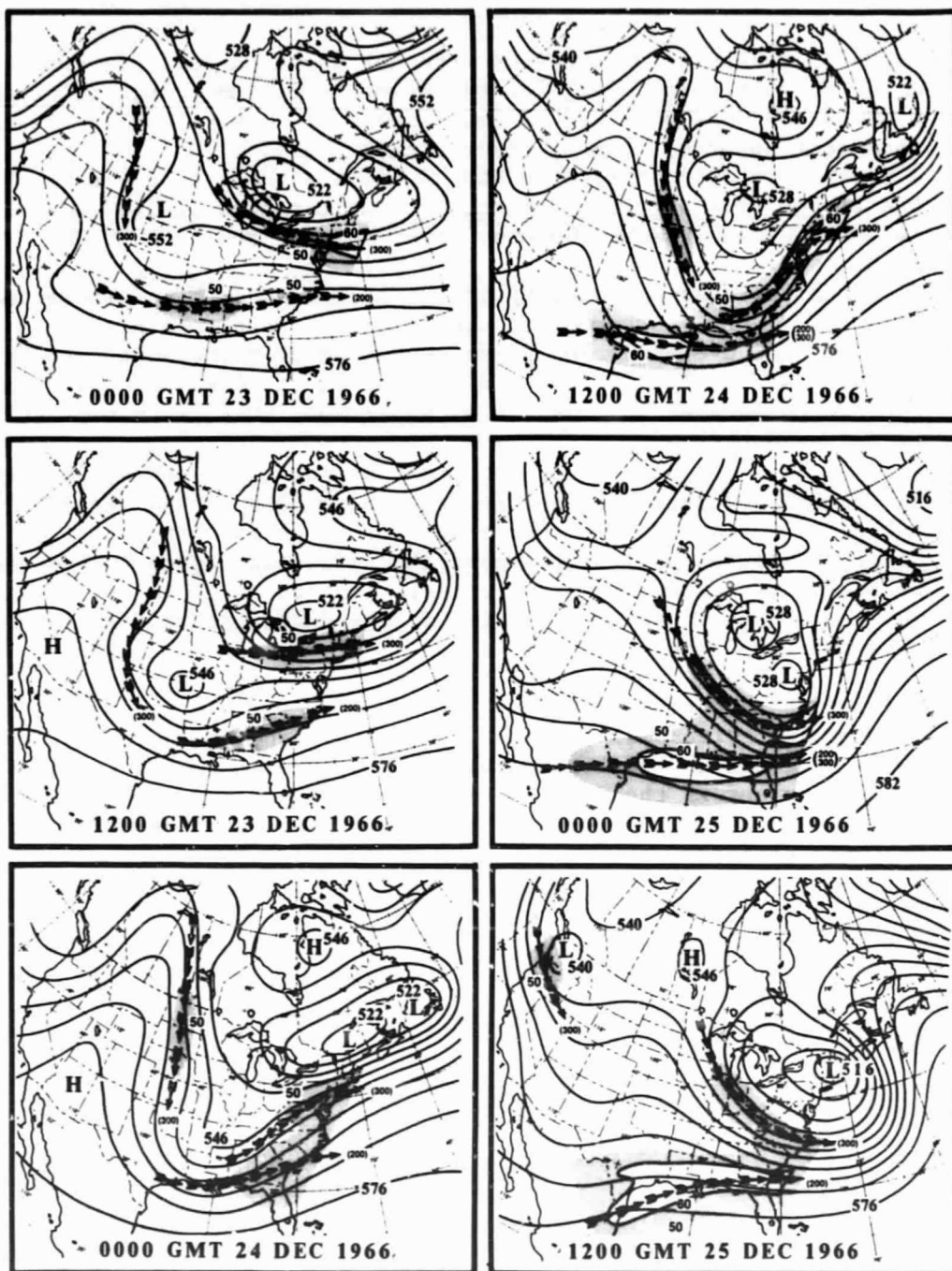
- o General features prior to cyclogenesis along the East Coast
 - A strong ridge was located just east of the West Coast and a short wave trough extended from Nebraska to New Mexico. A cold-core vortex was located just north of Lake Huron with an amplifying ridge across northeastern Canada. The combination of the Great Lakes vortex and the trough in the Plains states produced a significant region of confluence across the northern and eastern United States. The confluence appears to be associated with the cold surface anticyclone extending eastward into the Middle Atlantic states by 0000 GMT 24 December.
- o Characteristics of trough associated with East Coast cyclogenesis
 - The vortex over the Great Lakes extending to the Atlantic Coast on 23 December split into separate trough systems (similar to the January 1966 case) early on 24 December with one trough moving off Newfoundland and the other apparently retrograding toward Michigan. The short wave trough over the Plains states then appears to phase in with the trough system forming near Michigan.
 - A low center at 500 mb remained over Michigan as a new "cut-off" center developed over Maryland within the amplifying trough at 0000 GMT 25 December as the surface low deepened rapidly off the East Coast. This new center pivoted in a counterclockwise sense around the Michigan low and was located over New England where it deepened rapidly by 120 m in 12 h ending at 1200 GMT 25 December as the surface low continued to deepen off the New England coast. The change in orientation and development of a new 500 mb low center late on 24 December and 25 December was associated with the rapid deepening phase of the storm, which again appears to occur off the coast as a diffluent region becomes better defined east of the negatively tilted trough axis along the East Coast at 0000 GMT 25 December.
 - The amplitude of the upstream ridge over the western United States and the trough over the Central Plains states increased sharply by 0000 GMT 24 December as the trough drifted southeastward to the lower Mississippi Valley before the surface low intensified and moved up the East Coast.
 - The amplitude of trough and downstream ridge increased sharply over a 12 h period ending at 0000 GMT 24 December, prior to East Coast cyclogenesis, and increased moderately thereafter.
 - The half-wavelength between trough and downstream ridge decreased between 0000 GMT 24 December and 0000 GMT 25 December during the cyclogenetic period as the precipitation shield extended northeastward along the East Coast.

Upper-level wind analyses

- o Jet streak characteristics of the cyclone-associated trough and flanking ridges

- Large increases of wind speeds were not observed for this case.
 - A 200 mb subtropical jet, located downwind of the trough prior to 0000 GMT 24 December, had maximum speeds of 50 m s^{-1} , which is less than that observed in many other cases.
 - A newly developing axis of enhanced winds appears to the east of the trough axis across the Middle Atlantic states at 0000 GMT 24 December and reached 60 m s^{-1} over New England by 1200 GMT 24 December.
 - The areal coverage of wind speeds greater than 50 m s^{-1} increased after 0000 GMT 24 December as precipitation developed north and east of the developing low pressure system over the southeastern United States. This is especially true at the base and upstream of the trough axis at 1200 GMT 24 December and later, when two jet axes are identified.
 - By 0000 GMT 25 December, it appears that one major jet system at 300 mb has developed, extending from the middle of the United States to a position near the base of the trough over South Carolina, immediately upstream of the diffluent region to the east of the trough axis. Thus, it appears that the rapid development phase of the surface low occurred in the diffluent exit region of this complex jet system.
- o Other jet characteristics
- A polar jet streak was observed over the northeastern United States on 23 December in association with the confluent region south of the vortex across the Great Lakes and is associated with rising sea-level pressures and colder temperatures across the Middle Atlantic states.

500 MB HEIGHTS AND UPPER-LEVEL WINDS



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Fig. 32. The 500 mb geopotential height analyses and isotachs of maximum wind speeds for 0000 GMT 23 December, 1200 GMT 23 December, 0000 GMT 24 December, 1200 GMT 24 December, 0000 GMT 25 December, and 1200 GMT 25 December 1966. See Fig. 4 caption for details.

6-7 February 1967

21. 6-7 FEBRUARY 1967

o General Remarks

- Snowfall was produced from two separate storm systems. The first storm produced a narrow band of snow across the northern Mid-Atlantic states and southern New England with generally less than 10 cm. The storm ushered in the coldest air of the season in the Middle Atlantic states. The second storm produced heavy snowfall rates, but for a relatively short duration. Blizzard conditions developed across the Middle Atlantic and southern New England states as the second storm developed rapidly along the coast. This storm was the fastest mover of the entire sample.

o Regions with snow accumulations exceeding 10 in (25 cm)

- northern Virginia, northeastern West Virginia, central and northern Maryland, northern Delaware, southeastern Pennsylvania, parts of western Pennsylvania, New Jersey, extreme southeastern New York, Connecticut, Rhode Island, central and eastern Massachusetts, southeastern New Hampshire, and coastal Maine

o Regions with snow accumulations exceeding 20 in (51 cm)

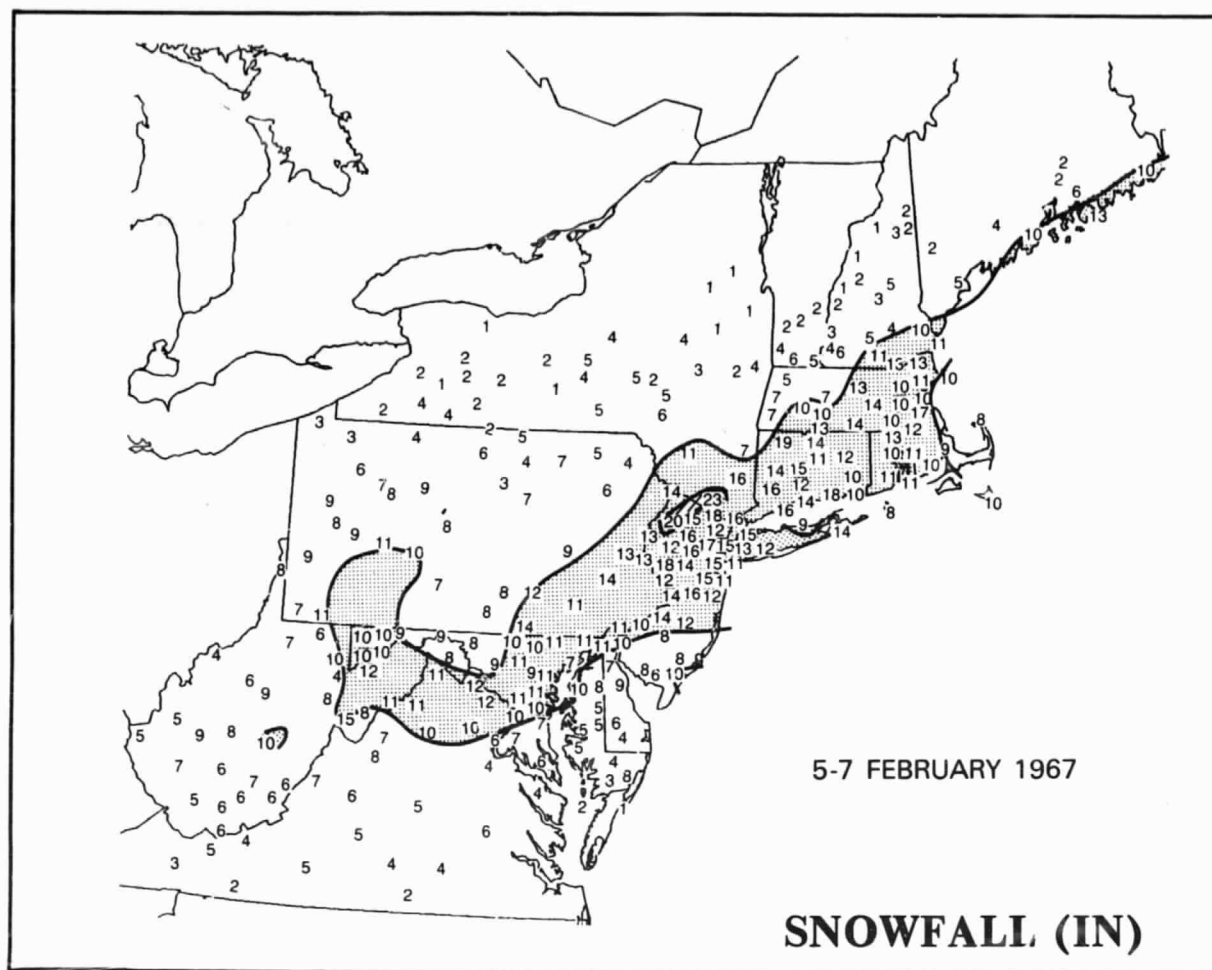
- scattered locations in northern New Jersey and southeastern New York

o Urban center snowfall amounts:

Washington, D.C.-Dulles Airport	11.8" (30 cm)
Baltimore, Md.	10.6" (27 cm)
Philadelphia, Pa.	9.9" (25 cm)
New York, N.Y.-Central Park	15.2" (39 cm)
Boston, Ma.	9.5" (24 cm)

o Other selected snowfall amounts:

Newark, N.J.	16.5" (42 cm)
Bridgeport, Ct.	14.9" (38 cm)
Worcester, Ma.	14.4" (37 cm)
Trenton, N.J.	13.8" (35 cm)
Allentown, Pa.	13.0" (33 cm)



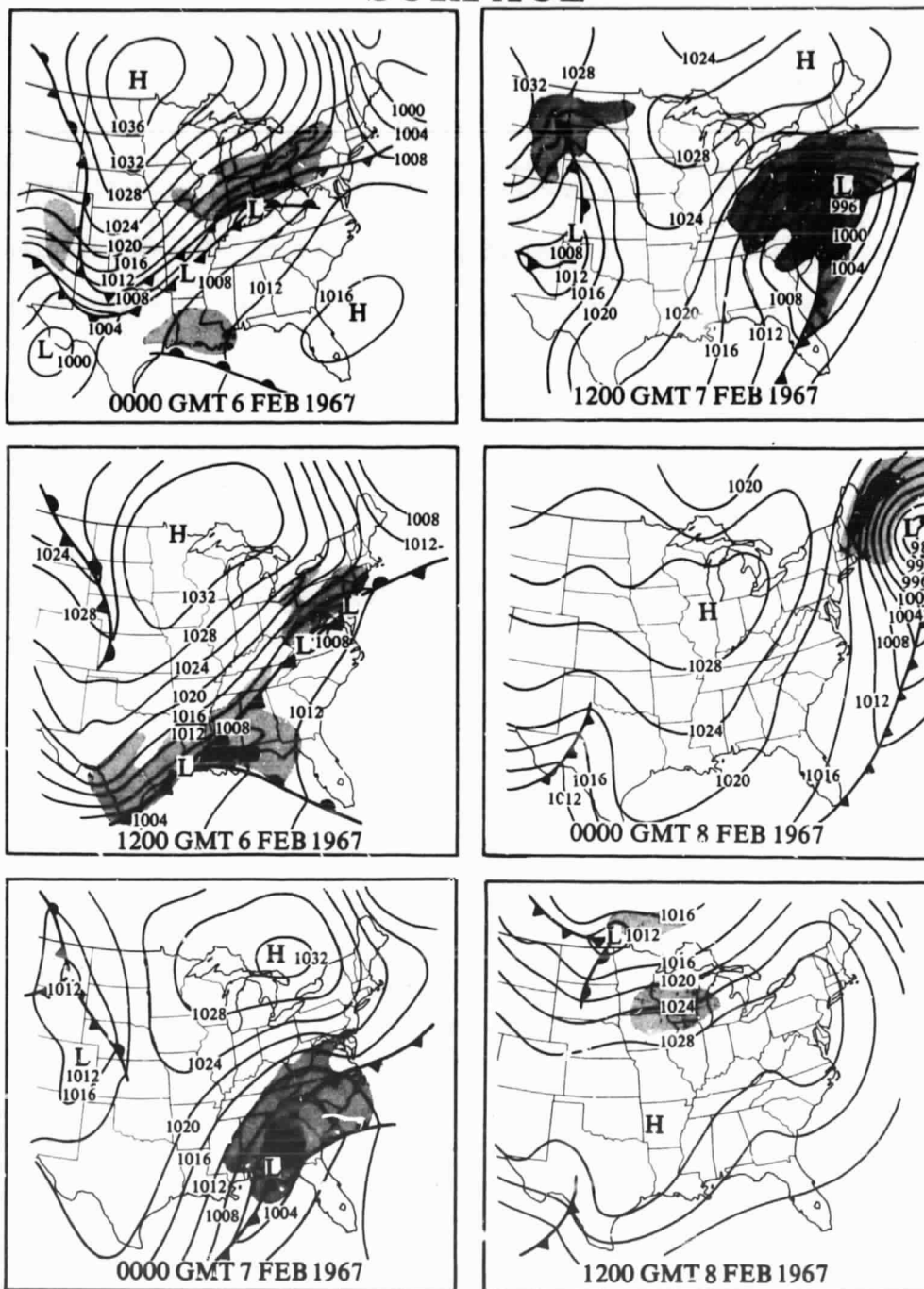
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Fig. 33. Total snow accumulations for 5 to 7 February 1967 (in). See Fig. 1 caption for details.

Surface characteristics

- o Type "A" (Miller, 1946)
- o Two cyclones
 - The first low propagated from southern Iowa to northern Kentucky to northern Virginia on 5 and 6 February along the edge of an intense cold front that moved southward into the Middle Atlantic states by 6 February. The surface low was weak and filled as it neared the East Coast, but still produced 5 to 10 cm accumulations across Pennsylvania and New York into the New York City area.
- o A cold anticyclone (1040 mb) was ushered into the northeastern United States following the first cyclone. Weak cold air damming was observed across the Middle Atlantic states late on the 6th and early on 7 February.
- o Coastal frontogenesis was not observed for this case.
- o The second low, which produced the heaviest snow, formed along the cold front as it reached the Gulf Coast. It moved very rapidly, propagating from northwestern Florida at 0000 GMT 7 February to off the Virginia coast in 12 h. It then moved to a position off the Maine coast by 0000 GMT 8 February, covering over 1000 km in 12 h. The surface low appeared to "jump" from central South Carolina to the Virginia coast between 0900 and 1200 GMT 7 February.
- o The area of precipitation expanded rapidly to the east and north as the surface low formed along the Gulf Coast and moved rapidly up the Atlantic coast. Heaviest precipitation was concentrated in an area initially just north of the cyclone center, but later approximately 200 km to the northwest of the low center. Heavy snow fell generally over a 12 h period or less, its brevity due to the storm's rapid movement. Temperatures between -7°C and -15°C and gale force winds created blizzard conditions across the Middle Atlantic states and southern New England on 7 February.
- o The cyclone deepened slowly as it moved across the southeastern United States and approached a deepening rate of 1 mb h⁻¹ after 1200 GMT 7 February once it was over the Atlantic Ocean.
- o The deepening rate for the storm center was less than other storms in the sample, but its rapid forward movement resulted in local pressure tendencies across southeastern Canada that rivaled the more rapidly deepening lows.

SURFACE



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Fig 34. Surface frontal and weather analyses for 0000 GMT 6 February, 1200 GMT 6 February, 0000 GMT 7 February, 1200 GMT 7 February, 0000 GMT 8 February, and 1200 GMT 8 February 1967. See Fig. 2 caption for details.

850 mb characteristics

- o Two separate 850 mb low centers reflect the two surface low pressure systems which produced snowfall for this case. The first low center weakened as it moved across the Ohio Valley to Pennsylvania by 1200 GMT 6 February. Its subsequent movement to the east was associated with the southward displacement of the 850 mb baroclinic zone to the Middle Atlantic region. Cold air was re-established across the northeastern United States following the passage of the low.
- o The second and more significant 850 mb low center developed in Texas along the southern edge of a narrow but intense temperature gradient that had moved south and positioned itself from a line extending from Texas to the lower Ohio Valley to the Middle Atlantic states at 1200 GMT 6 February as the surface and 850 mb lows were near the Gulf Coast.
- o The second low deepened slowly as it drifted northeastward to the Middle Atlantic coast before deepening more rapidly once it was well off the coast.
- o A weak "S"-shaped isotherm pattern is observed at 850 mb at 1200 GMT 7 February. The warm advection was rather intense along the Middle Atlantic coast.
- o The low center remained near the 0°C isotherm, especially when it was over the East Coast at 1200 GMT 7 February.
- o A 20 to 25 m s^{-1} north to northeasterly jet accompanied the development of the 850 mb low over Texas early on 6 February. A 30 m s^{-1} southerly jet over eastern North Carolina and a general increase of wind speeds occurred as the 850 mb low neared the Atlantic coast at 1200 GMT 7 February, enhancing the warm advection and moisture transport into the developing precipitation area.

850 MB

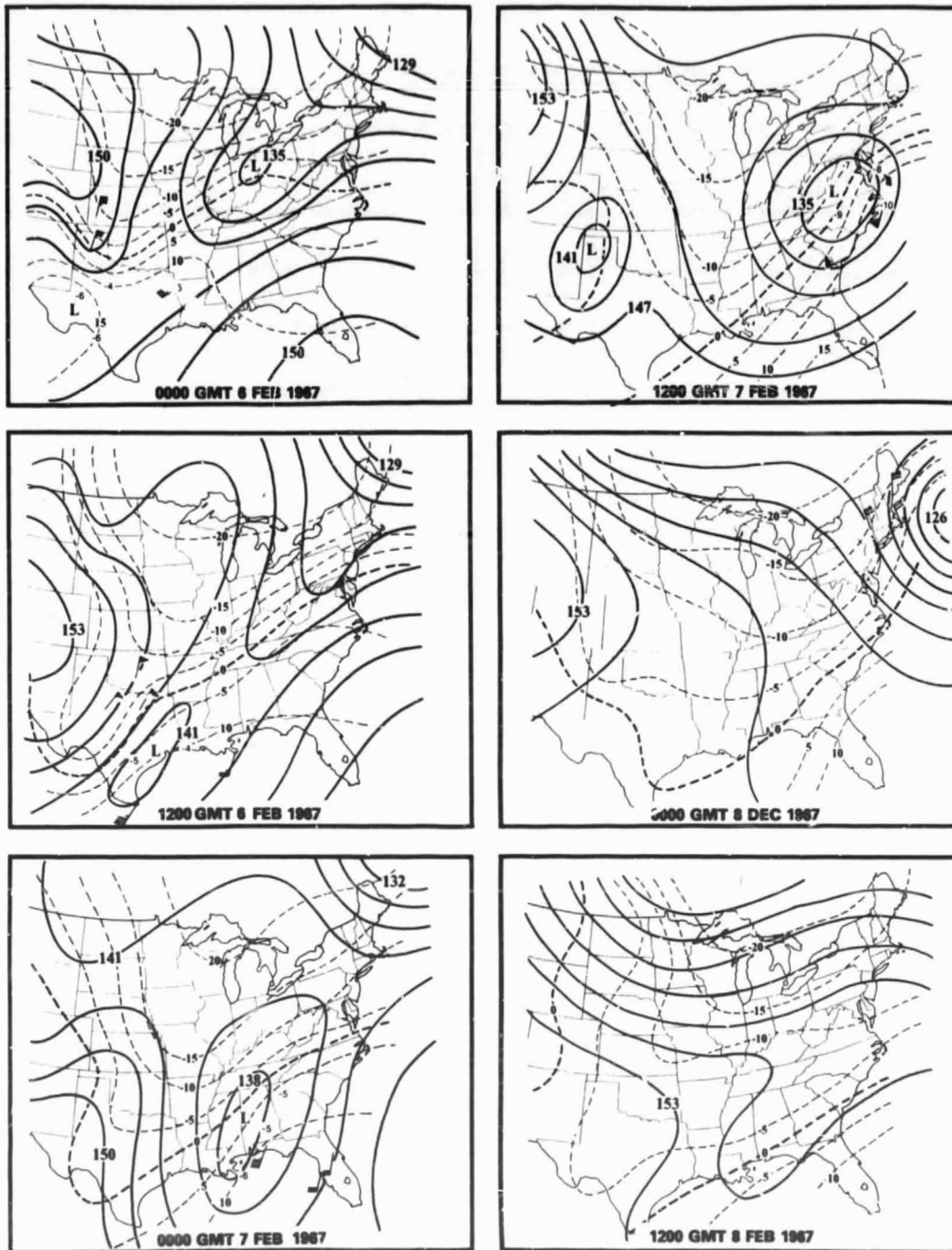


Fig. 35. The 850 mb analyses for 0000 GMT 6 February, 1200 GMT 6 February, 0000 GMT 7 February, 1200 GMT 7 February, 0000 GMT 8 February, and 1200 GMT 8 February 1967. See Fig. 3 caption for details.

500 mb geopotential height characteristics

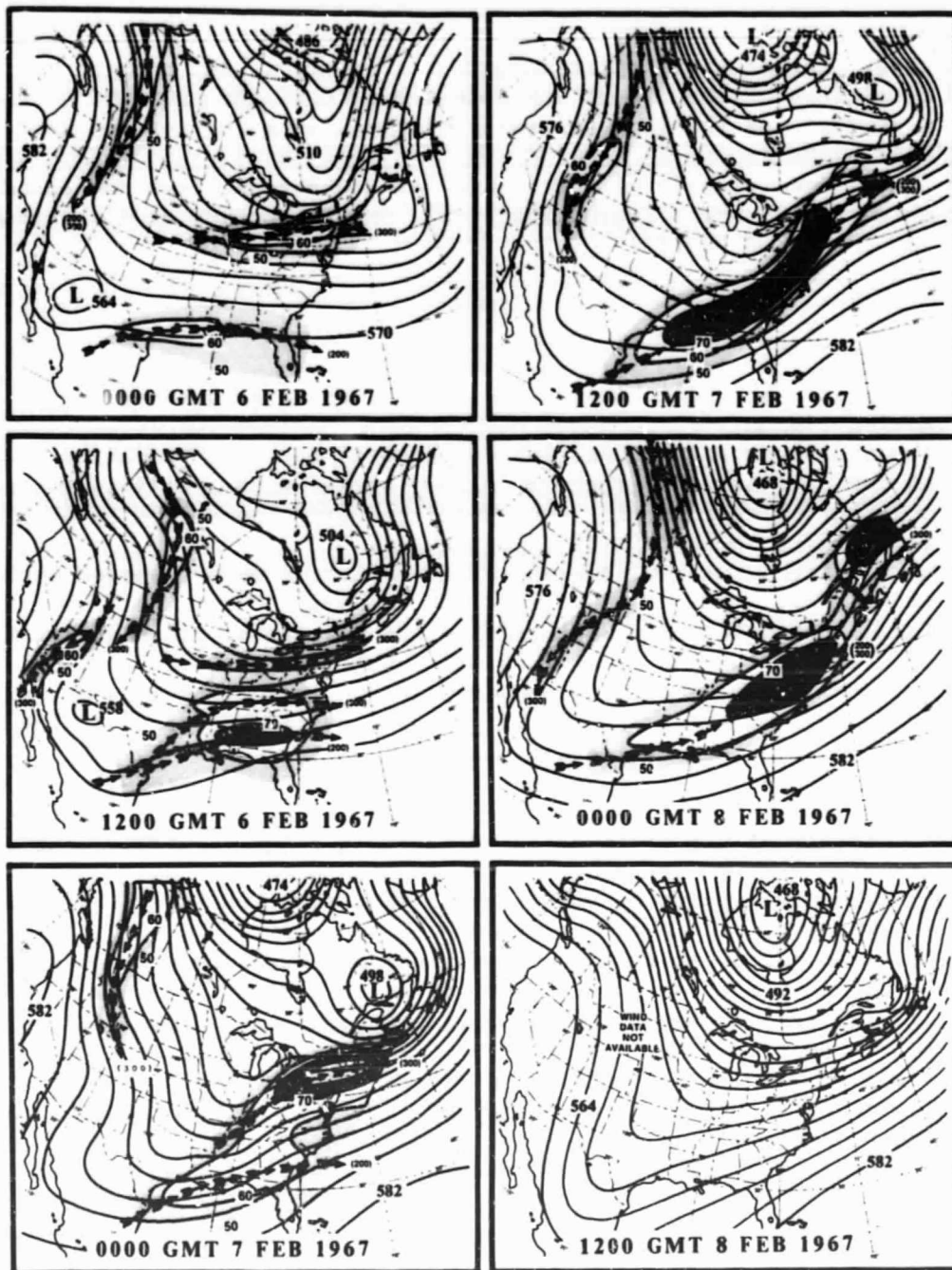
- o General features prior to cyclogenesis along the East Coast
 - The development of a vortex across eastern Canada was associated with highly confluent flow across southeastern Canada and the northeastern United States. An anticyclone and cold surface temperatures moved toward New England in association with the confluent upper-level flow and preceded the onset of precipitation from the East Coast storm. A short wave trough over the southwestern United States and another trough propagating southeastward to the east of a high amplitude ridge across the western United States set the stage for incipient cyclogenesis.
- o Characteristics of trough associated with East Coast cyclogenesis
 - The first weak cyclone that propagated just to the south of New York City by 1200 GMT 6 February was associated with a weak trough over the Ohio Valley. This trough appeared to stretch out and weaken within the strongly confluent flow over New England by 1200 GMT 6 February, coinciding with the weakening surface low pressure system.
 - The second major cyclone was associated with a trough system that was less well-defined than in the other cases studied in this paper. The trough deepened over the central United States, upstream of an amplifying ridge along the East Coast. However, there appears to be several "short waves" imbedded in the trough, especially before 0000 GMT 7 February.
 - The surface cyclone developed during the merger of two troughs on 6 February, where
 - (A) a closed center trough over northwestern Mexico "opened up" and lifted northeastward, while
 - (B) another trough propagated southeastward across the Rocky Mountains in the northwesterly flow downwind of the ridge along the West Coast.
 - The merger was not distinct as two adjacent trough axes were observed at 1200 GMT 6 February with one axis extending from Oklahoma to southwestern Texas; the other over eastern Texas into Mexico. However, the trough became better defined over the Ohio and Tennessee Valleys by 1200 GMT 7 February as the surface low developed and moved rapidly up the Atlantic coast. The trough lifted northeastward and was located over eastern Canada by 1200 GMT 8 February.
 - No closed center at 500 mb developed and no distinct minimum in the geopotential field was observed until 1200 GMT 8 February across extreme eastern Canada.
 - Unlike most of the other cases, this trough did not have a marked diffluent region downstream of the trough axis until it reached eastern Canada, even though the trough developed a slight negative tilt after 1200 GMT 7 February. The lack of this feature may be related to the rapid movement of the entire storm system.
 - The geopotential gradients at the base of the trough increased after 0000 GMT 7 February during the period of rapid cyclogenesis.

- Large increases of amplitude were not observed, but ridging downstream of the trough was observed at 0000 and 1200 GMT 7 February as the cyclone was developing along the northeastern Gulf of Mexico.
- The half-wavelength of the trough and downstream ridge decreased between 1200 GMT 6 February and 1200 GMT 7 February as the surface low developed rapidly.

Upper-level jet characteristics

- o Jet streak characteristics of the cyclone-associated trough and flanking ridges
 - The southeastward propagating trough over the western United States on 5-6 February that appears to have merged with the lifting trough over northwestern Mexico was associated with several 50 to 60 m s⁻¹ jet streaks upwind of the trough axis.
 - Large increases in wind speed at upper levels were observed with this case.
 - (A) A subtropical jet amplified in the downstream ridge during the 24 h period ending at 1200 GMT 6 February with wind speeds across the southeastern United States increasing by greater than 20 m s⁻¹. The amplification occurred as precipitation developed across the Gulf Coast.
 - (B) An increase in wind speeds occurred over the northeastern United States at 0000 GMT 7 February as an 80 m s⁻¹ jet streak formed at the crest of the downstream ridge in highly confluent flow during cyclogenesis over the southeastern United States. The development of this wind maximum occurred as precipitation was expanding northward along the East Coast.
 - (C) Wind speeds at 200 and 300 mb increased uniformly to greater than 70 m s⁻¹ along the East Coast at 1200 GMT 7 February as the cyclone moved off the Virginia coast and intensified rapidly.
 - Between 0000 GMT 7 February and 0000 GMT 8 February, the surface low center is found in the exit region of the jet to the south of the trough and the entrance region of a separate jet streak over New England and southeastern Canada (see Part 1 for a detailed example of how this orientation influences vertical motion).
- o Other jet characteristics
 - A 60 m s⁻¹ polar jet streak is analyzed from 1200 GMT 5 February to 1200 GMT 6 February across the Ohio Valley and New England within the confluent region over the Great Lakes as a surface high pressure system became entrenched across the northeastern United States prior to East Coast cyclogenesis.

500 MB HEIGHTS AND UPPER-LEVEL WINDS



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Fig. 36. The 500 mb geopotential height analyses and isotachs of maximum wind speeds for 0000 GMT 6 February, 1200 GMT 6 February, 0000 GMT 7 February, 1200 GMT 7 February, 0000 GMT 8 February, and 1200 GMT 8 February 1967. See Fig. 4 caption for details.

9-10 February 1969

2j. 9-10 FEBRUARY 1969

o General Remarks

- This storm is known as the "Lindsay Storm" in New York City since the city's mayor ran into political misfortune after certain sections of city remained unplowed for at least a week following the storm. The storm was poorly forecast in New York City as forecasters first thought precipitation would fall primarily as rain. When it appeared that snow would be the predominant form of precipitation on 9 February, forecast snowfall amounts persistently lagged actual totals as snow continued long past estimates of when it would cease to fall. The rapid development and increasingly slow movement brought paralyzing snow and increasing winds from northern New Jersey to New England.

o Regions with snow accumulations exceeding 10 in (25 cm)

- northern New Jersey, southeastern New York (except eastern Long Island), most of Connecticut, central and northern Rhode Island, Massachusetts (except the southeast), Vermont (except the northwest), New Hampshire, and southern and central Maine

o Regions with snow accumulations exceeding 20 in (51 cm)

- parts of the New York City and Boston, Ma. metropolitan areas, western Connecticut, western and eastern Massachusetts, southern Vermont, northern Rhode Island, eastern New Hampshire, and southern Maine

o Urban center snowfall amounts:

Washington, D.C.-Dulles Airport	5.0" (13 cm)
Baltimore, Md.	3.0" (8 cm)
Philadelphia, Pa.	2.9" (7 cm)
New York, N.Y.-Kennedy Airport	20.2" (51 cm)
Boston, Ma.	11.1" (28 cm)

o Other selected snowfall amounts:

Bedford, Ma.	25.0" (64 cm)
Portland, Me.	21.5" (55 cm)
Bridgeport, Ct.	17.7" (45 cm)
Hartford, Ct.	15.8" (40 cm)
Worcester, Ma.	15.6" (40 cm)

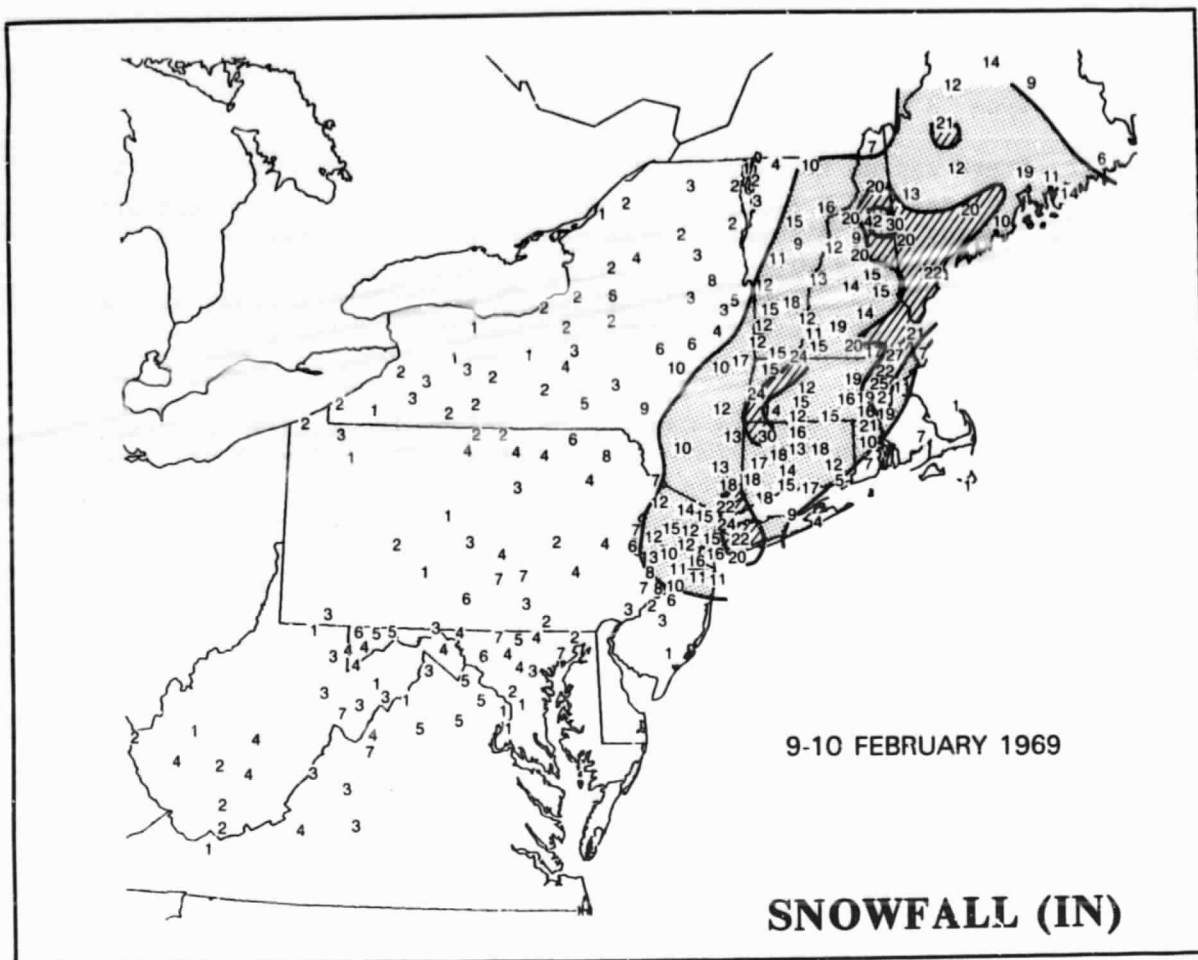


Fig. 37. Total snow accumulations for 9 to 10 February 1969 (in). See Fig. 1 caption for details.

Surface characteristics

- o Type "B" (Miller, 1946)
- o There was no bitterly cold air, either preceding or following the passage of this storm. A 1022 mb anticyclone drifted off New England by 0000 GMT 9 February, which resulted in southeasterly winds along the coast late on 8 February. The winds backed to northeasterly along the Atlantic coast as the secondary low developed rapidly and moved up the coast on 9 February.
- o Weak cold air damming was observed along the Middle Atlantic Coast late on 8 February as the moderately cold high pressure system moved across the New England states.
- o The primary surface low propagated east-northeastward from Oklahoma to Kentucky in 24 h ending at 0000 GMT 9 February, covering approximately 1000 km.
 - Little change in central pressure was noted during this period, but the surface low was associated with moderate to heavy rain from Missouri into Ohio on 8 February.
 - This low weakened rapidly as the secondary low formed between 0000 GMT and 1200 GMT 9 February, and disappeared 9 h after secondary cyclogenesis commenced.
- o The secondary low pressure system formed along the Southeast coast between 1800 GMT 8 February and 0000 GMT 9 February as heavy rains developed in the Carolinas. Mixed snow and rain developed across the Middle Atlantic states between 0000 GMT and 0600 GMT 9 February, with predominantly wet snow in northern Virginia, central Maryland, eastern Pennsylvania, and New Jersey. Precipitation amounts were generally light to moderate in these locations. Heavy snow developed from New Jersey northward.
 - The secondary low developed inland across Georgia along a front that cannot strictly be called a coastal front. It appears that the cyclone formed along the warm front of the primary low pressure system. However, there was some tendency for the front to extend itself near the Southeast coast where small land-sea air temperature differences were observed.
 - The low moved northeastward from the North Carolina coast to just off Long Island by 0000 GMT 10 February, and then east of Massachusetts by 1200 GMT 10 February.
 - The low deepened 32 mb over 18 h, reaching 970 mb by 0000 GMT 10 February just east of Long Island.
 - The forward motion of the secondary low slowed during 9 February, moving only 200 km in 12 h, prolonging the heavy snowfall from New York City to New England.

SURFACE

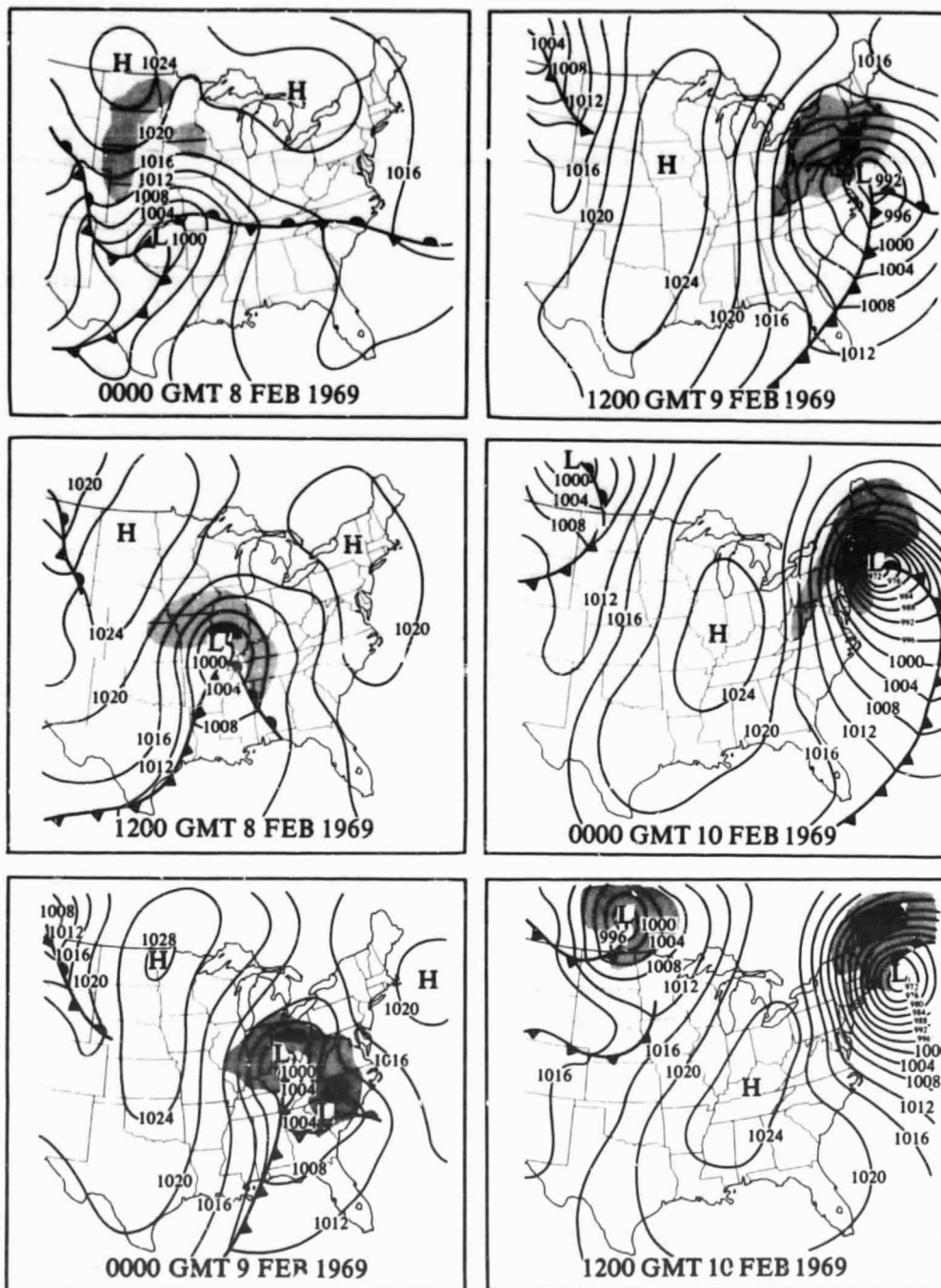


Fig. 38. Surface frontal and weather analyses for 0000 GMT 8 February, 1200 GMT 8 February, 0000 GMT 9 February, 1200 GMT 9 February, 0000 GMT 10 February, and 1200 GMT 10 February 1969. See Fig. 2 caption for details.

850 mb characteristics

- o Due to weak temperature gradients, only weak cold advections were observed across the Northeast prior to East Coast cyclogenesis on 8 February.
- o The 850 mb low center was located at the edge of an intense temperature gradient over the Southern Plains by 0000 GMT 8 February that weakened as the low drifted to the east in the following 24 h.
- o A warm wedge of air was located north and east of the 850 mb low center in the Ohio Valley on 8 February prior to East Coast cyclogenesis.
- o The 850 mb low went through a period of accelerated deepening that began after 1200 GMT 8 February as the primary surface low was crossing the Ohio Valley. The 850 mb deepening rate reached a maximum between 1200 GMT 9 February and 0000 GMT 10 February ($-150 \text{ m (12 h)}^{-1}$), the same period in which the surface low deepened by 20 mb off the Middle Atlantic and southern New England coasts.
- o Secondary low development across the southeastern United States is hinted at 0000 GMT 9 February by an elongated region of height falls from Ohio to South Carolina. Secondary development along the Carolina coasts is also supported by the large temperature gradient located from Georgia to Virginia, south and east of the main 850 mb low center.
- o An "S" shape to the isotherms was evident by 1200 GMT 9 February at the start of rapid cyclogenesis.
- o The 0°C isotherm was consistently located near the 850 mb low center.
- o Southwesterly winds across the southeastern United States increased in speed in conjunction with the enhanced height fall center and outbreak of precipitation across the Carolinas and Virginia by 0000 GMT 9 February.
- o Easterly winds in the vicinity of the 850 mb low center increased markedly in speed during the 12 h period ending at 0000 GMT 10 February when rapid surface cyclogenesis was in progress and as heavy precipitation was spreading across New York and New England.

850 MB

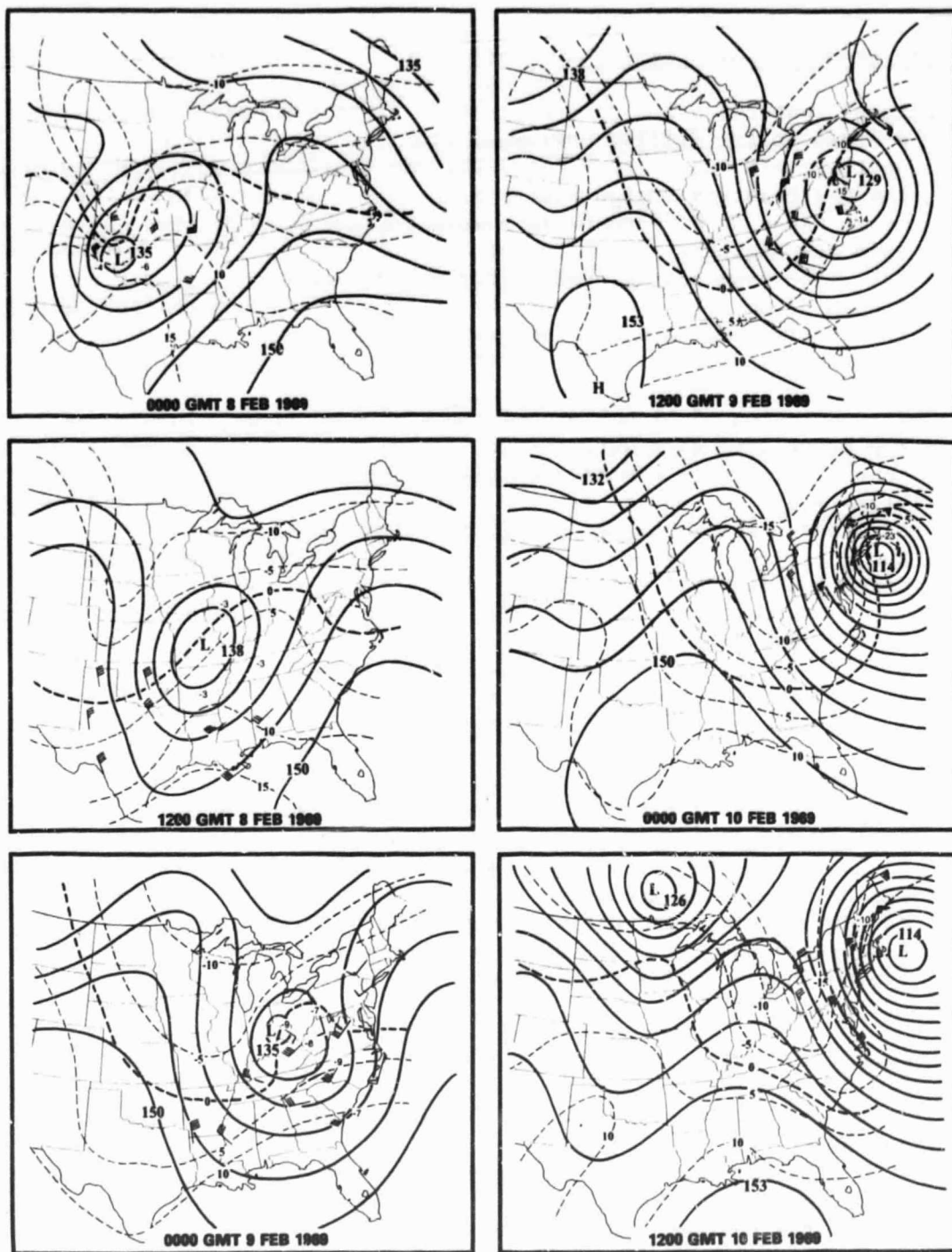


Fig. 39. The 850 mb analyses for 0000 GMT 8 February, 1200 GMT 8 February, 0000 GMT 9 February, 1200 GMT 9 February, 0000 GMT 10 February, and 1200 GMT 10 February 1969. See Fig. 3 caption for details.

500 mb geopotential height characteristics

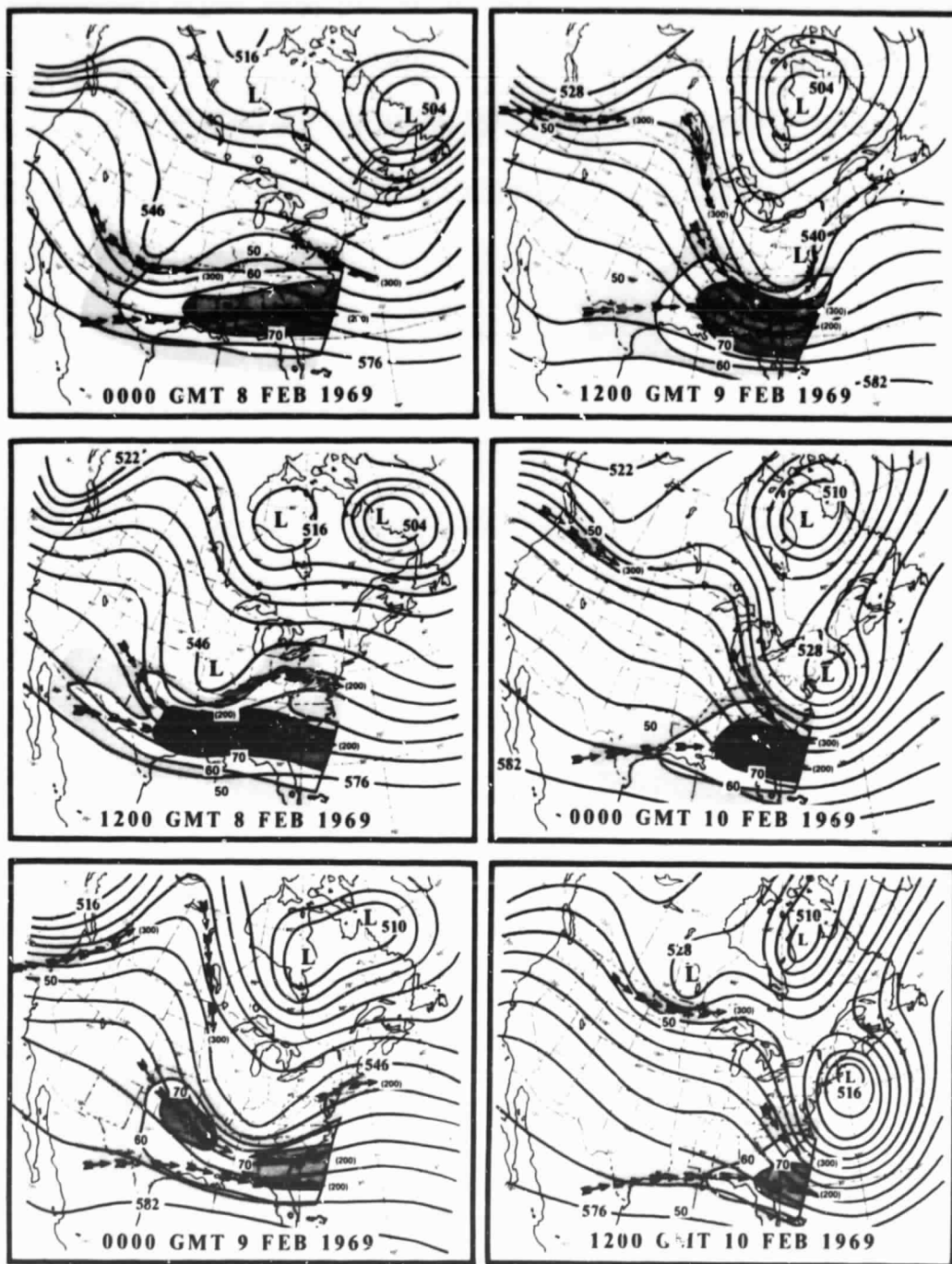
- o General features prior to cyclogenesis along the East Coast
 - A large vortex drifted northward from eastern Canada to northeastern Canada by 9 February. No confluence was observed over the northeastern United States with only weak confluence over the Great Lakes on 8 February as a weak surface high drifted eastward into New England. This lack of confluence represents a marked deviation from nearly every other major snowstorm. A progressive trough of moderate amplitude that spawned the storm drifted across the central United States and was located immediately downstream of an amplifying ridge in the northwestern United States.
- o Characteristics of trough associated with East Coast cyclogenesis
 - The travelling open wave trough propagated eastward from the Central Plains to the Middle Atlantic Coast on 9 February as the primary cyclone moved into the Ohio Valley on 8 February and the secondary cyclone formed along the East Coast early on 9 February.
 - Rapid cyclogenesis commenced as the trough approached the East Coast and deepened rapidly on 9 February.
 - The geopotential minimum of the trough center deepened from 5360 m at 1200 GMT 9 February to 5120 m at 1200 GMT 10 February during the period of greatest surface intensification.
 - By 1200 GMT 9 February, the diffluent region east of the trough axis (just south of New York) became well-defined with the onset of rapid deepening of the surface low along the Virginia coast.
 - The amplitude of the trough along the northeastern United States and the downstream ridge offshore increased at 0000 GMT 10 February as the axis of the ridge surged northward east of New England while the intense storm was located off Long Island.
 - The half-wavelength between the trough nearing the East Coast and the downstream ridge off the East Coast decreased at 1200 GMT 9 February as precipitation spread across the Northeast and the cyclone began to deepen rapidly.

Upper-level jet characteristics

- o Jet streak characteristics of the cyclone-associated trough and flanking ridges
 - A subtropical jet at 200 mb downstream of the trough axis (0000 GMT 8 through 0000 GMT 9 February) did not amplify as it propagated across the southern United States.
 - Another jet upstream of the trough axis (over Texas and New Mexico on 8 February) appears to propagate with the trough on 8 February and then merge with the subtropical jet along the Southeast coast by 1200 GMT 9 February as the secondary surface low and associated precipitation developed in the diffluent exit region of this jet system.
 - There is the tendency for wind speeds to increase at and upstream of the trough axis between 0000 GMT 8 February and 0000 GMT 9 February, prior to the East Coast surface development.

- o Other jet characteristics
 - A jet streak in the poorly-defined confluent region extending from the Great Lakes to the East Coast prior to cyclogenesis on 8 February was rather weak.

500 MB HEIGHTS AND UPPER-LEVEL WINDS



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Fig. 40. The 500 mb geopotential height analyses and isotachs of maximum wind speeds for 0000 GMT 8 February, 1200 GMT 8 February, 0000 GMT 9 February, 1200 GMT 9 February, 0000 GMT 10 February, and 1200 GMT 10 February 1969. See Fig. 4 caption for details.

23-28 February 1969

2k. 23-28 FEBRUARY 1969

o General Remarks

- This was an unusual storm due to its slow movement, moderate intensity, erratic intensification, lack of large thermal contrast at the surface, and a chaotic upper-level geopotential pattern. The storm produced excessive amounts of snow across New England with greater than 75 cm accumulations across large sections of eastern Massachusetts, New Hampshire, and Maine.

o Regions with snow accumulations exceeding 10 in (25 cm)

- central and northern Connecticut and Rhode Island, central and eastern Massachusetts (except Cape Cod and the Islands), eastern Vermont, New Hampshire, and Maine

o Regions with snow accumulations exceeding 20 in (51 cm)

- eastern Massachusetts, northeastern Vermont, New Hampshire, and Maine

o Urban center snowfall amounts:

Philadelphia, Pa.	1.9" (5 cm)
New York, N.Y.-La Guardia	1.7" (4 cm)
Boston, Ma.	26.3" (67 cm)

o Other selected snowfall amounts:

Mt. Washington, N.H.	97.8" (248 cm)
Pinkham Notch, N.H.	77.3" (196 cm)
Long Falls Dam, Me.	56.0" (142 cm)
Old Town, Me.	43.6" (111 cm)
Rockport, Ma.	39.0" (99 cm)
Portland, Me.	26.9" (68 cm)

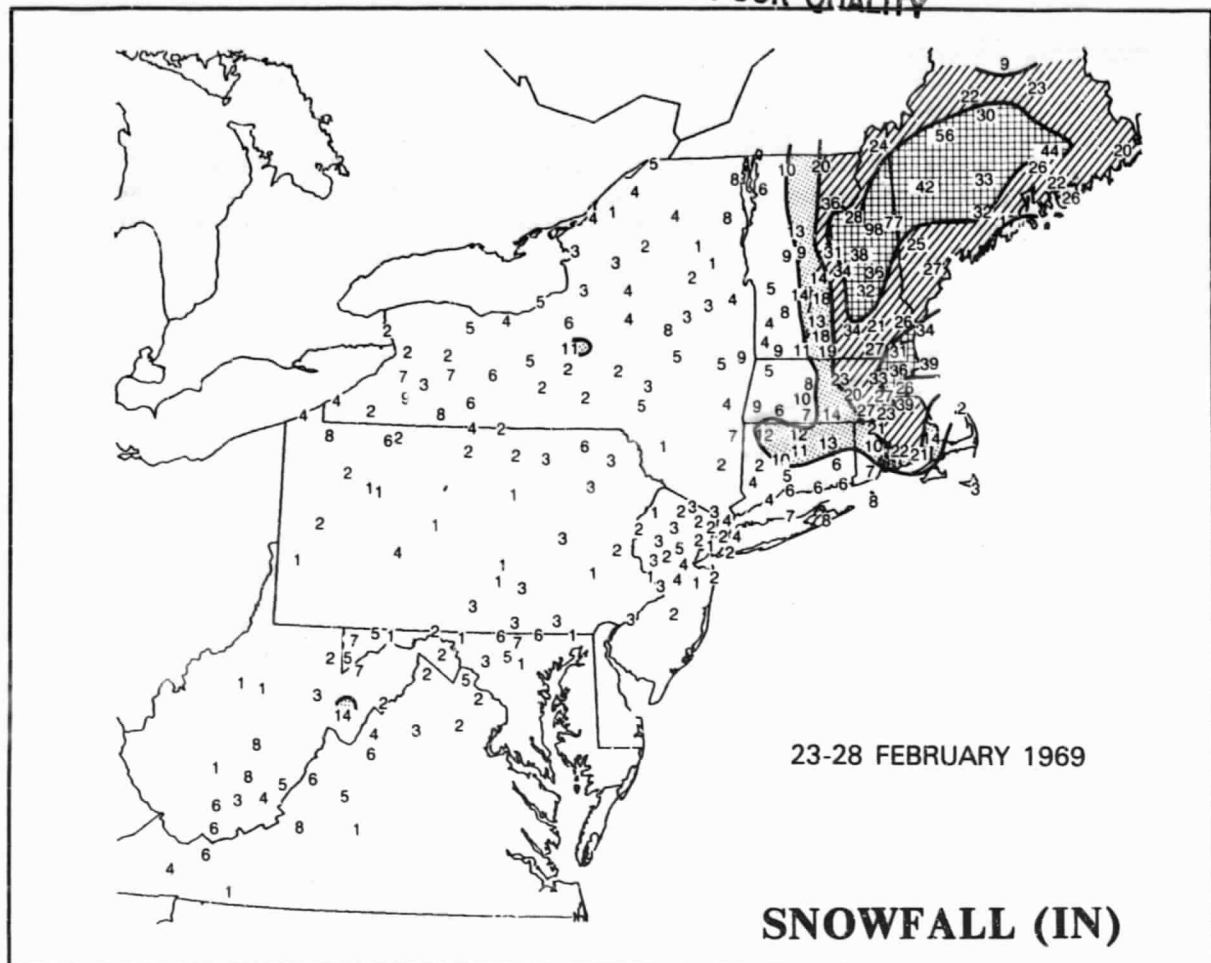


Fig. 41. Total snow accumulations for 23 to 28 February 1969 (in). See Fig. 1 caption for details.

Surface characteristics

- o Type "A" or "B" (Miller, 1946)
- o A large anticyclone was anchored over Hudson Bay prior to and during cyclogenesis (1040 mb), but the air immediately along the East Coast during the storm period was maritime in origin with temperatures generally between -5° and $+5^{\circ}\text{C}$.
- o A ridge of high pressure extending down the East Coast prior to cyclogenesis was evidence of cold air damming on 22 and 23 February.
- o The surface low was an ill-defined system that appears to fit more into a Type "B" than "A" classification (Miller, 1946) as an inverted trough initially in the Ohio Valley slowly developed into a weakening low center which meandered northeastward with no frontal structure and only some light precipitation on 23 February. A secondary inverted trough and coastal front developed along the Southeast Coast by 1200 GMT 23 February.
 - The surface low deepened slowly ($-4 \text{ mb (12 h)}^{-1}$) as it propagated from near Virginia to east of New Jersey between 0000 and 1200 GMT 24 February.
 - The low then deepened more rapidly in the following 12 h (1200 GMT 24 February to 0000 GMT 25 February) off the southern New England coast as its central pressure fell 10 mb to 994 mb.
 - Little deepening occurred thereafter as the surface low moved very slowly after 1200 GMT 24 February, averaging only 250 km in 24 h.
 - The cyclone meandered off the southeastern New England coast for the following 3 to 4 days, prolonging the heavy snowfall in eastern New England.
- o Sea-level pressure gradients to the north and northeast of the surface low were moderately intense, especially at 0000 GMT 25 February.

SURFACE

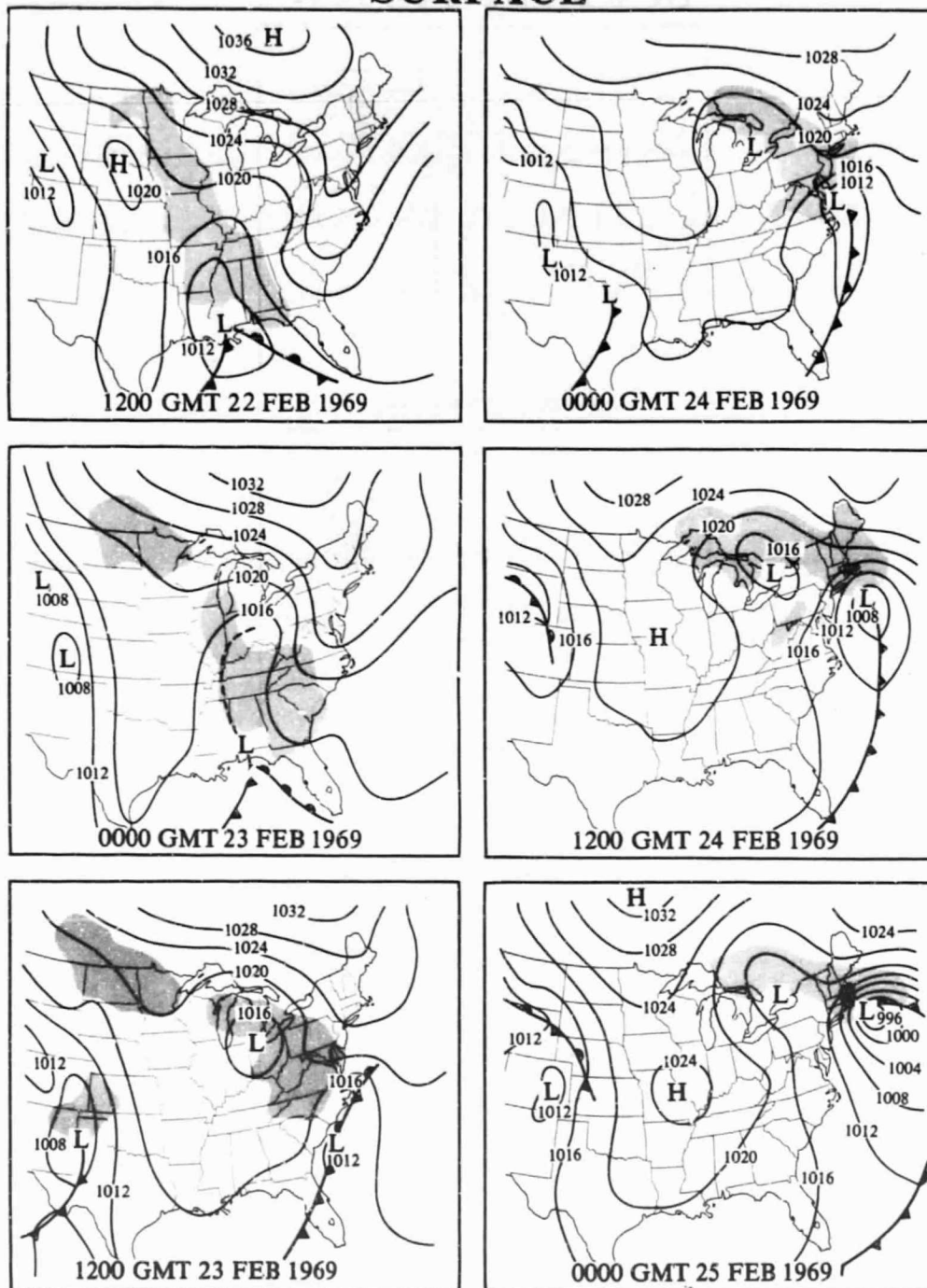


Fig. 42. Surface frontal and weather analyses for 1200 GMT 22 February, 0000 GMT 23 February, 1200 GMT 23 February, 0000 GMT 24 February, 1200 GMT 24 February and 0000 GMT 25 February. See Fig. 2 caption for details.

SURFACE (CONT.)

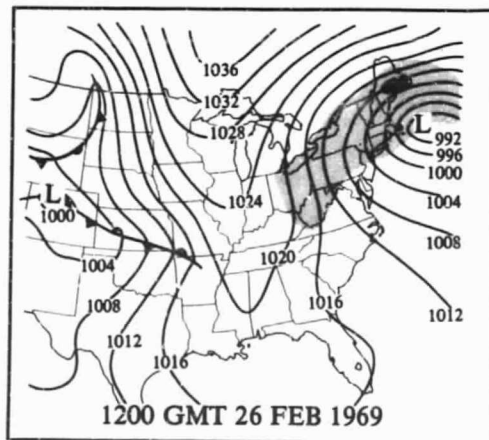
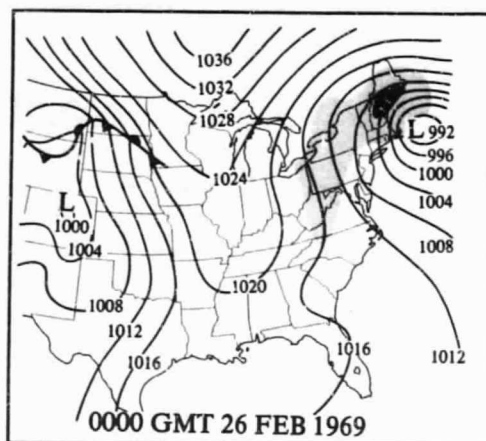
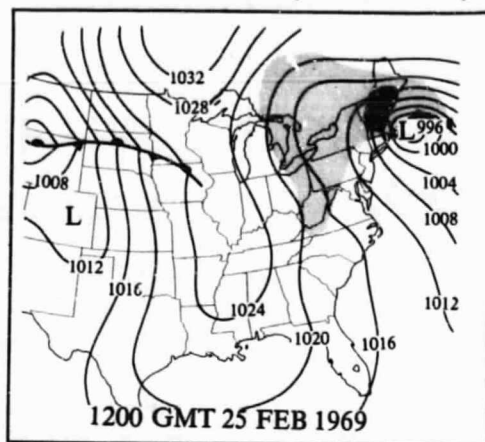
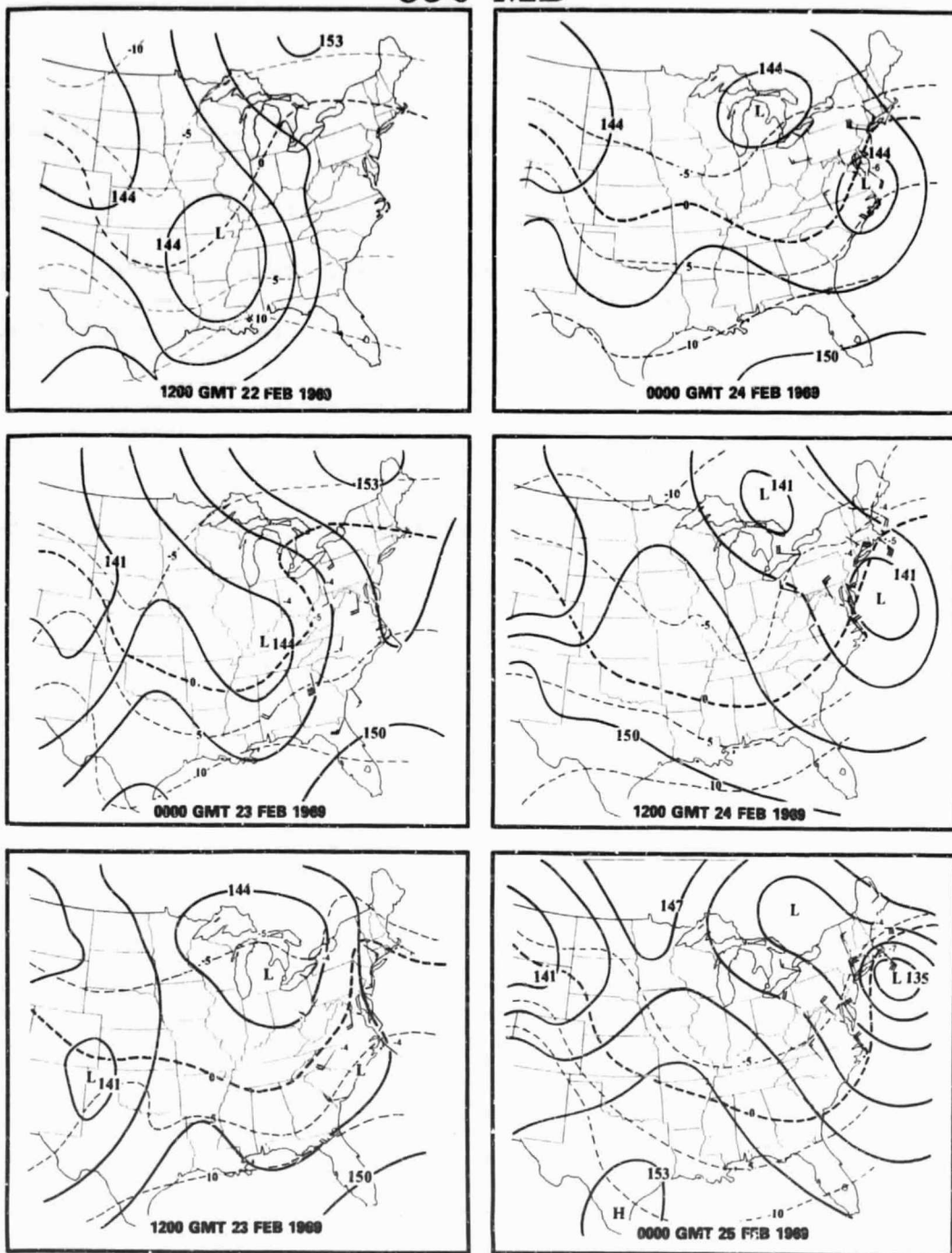


Fig. 42. Surface frontal and weather analyses for 1200 GMT 25 February, (cont.) 0000 GMT 26 February, and 1200 GMT 26 February 1969. See Fig. 2 caption for details.

850 mb characteristics

- o Cold air advection associated with northwesterly flow at 850 mb was not observed over the northeastern United States prior to the storm.
- o Two separate 850 mb low centers were observed for this case.
- o The first and weaker low moved northward from Kentucky to Michigan on 23 February. This 850 mb low was associated with the inverted trough, surface low, and light precipitation across the Ohio Valley. The low was imbedded in a weak horizontal temperature field, propagated well to the north and west of the 0°C isotherm, and did not deepen appreciably.
- o A second 850 mb low formed along the enhanced temperature gradient near the coast by 1200 GMT 23 February. The development of a secondary low center near the Atlantic coast in a thermal field more intense than near the first low center in Michigan supports a contention that this storm resembles a type "B" development (Miller, 1946) more than type "A."
- o The second low deepened slowly as it drifted up the East Coast, but more rapid deepening ensued after 1200 GMT 24 February. This low initially developed on the warm side of the 0°C isotherm, but was located closer to 0°C during cyclogenesis near New England late on 24 February and on 25 February.
- o A weak "S"-shaped 850 mb isotherm pattern was observed as the surface low developed along the East Coast from 0000 GMT 24 February to 0000 GMT 25 February.
- o This cyclone evolved in the weakest temperature field of the survey, but a very narrow region of intense temperature gradient formed over New England by 1200 GMT 24 February as heavy precipitation developed across eastern New England.
- o Southeasterly to easterly winds and associated moisture transports increased to the north of the coastal low center on 24 and 25 February as the system intensified and heavy snow fell across New England.

850 MB



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Fig. 43. The 850 mb analyses for 1200 GMT 22 February, 0000 GMT 23 February, 1200 GMT 23 February, 0000 GMT 24 February, 1200 GMT 24 February and 0000 GMT 25 February. See Fig. 3 caption for details.

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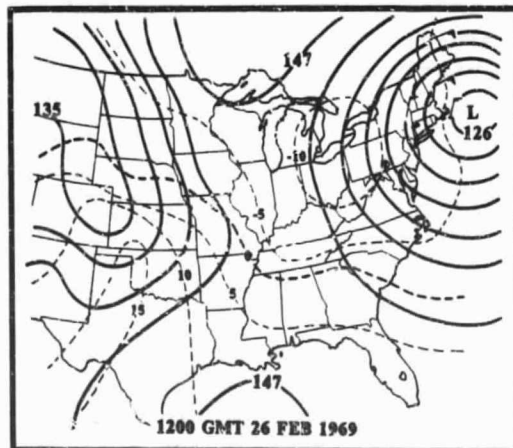
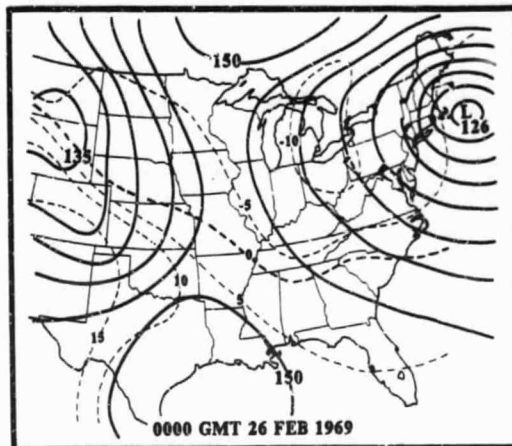
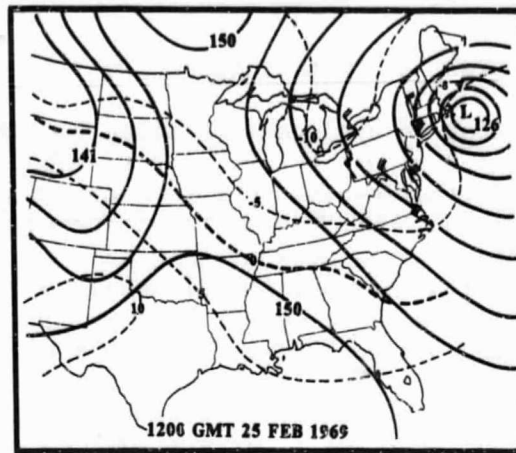


Fig. 43. The 850 mb analyses for 1200 GMT 25 February, 0000 GMT (cont.) 26 February, and 1200 GMT 26 February 1969. See Fig. 3 caption for details.

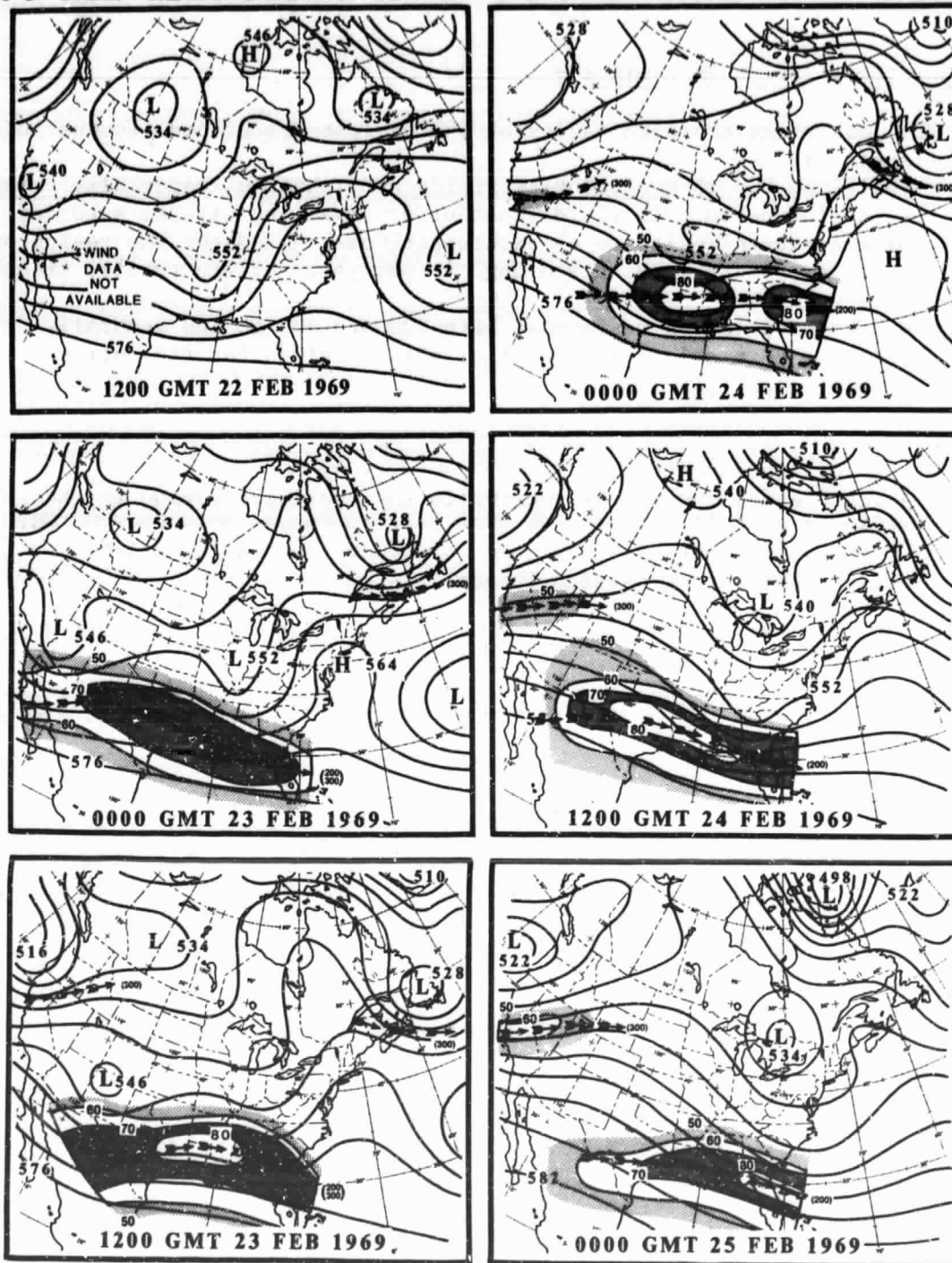
500 mb geopotential height characteristics

- o General features prior to cyclogenesis along the East Coast
 - Many features at 500 mb are not similar to the coherent trough/ridge patterns of other cases. Prior to cyclogenesis (at 0000 GMT 23 February), several troughs were found across the United States and Canada. A trough in southeastern Canada was associated with strong confluence that appears to influence the large anticyclone over eastern Canada on 23 February. Two troughs over the central and southern United States influenced the growth of the East Coast storm within the next several days. The pre-cyclogenetic period also included a major trough off the West Coast, a cut-off low center north of Montana, and a cut-off low center in the western Atlantic.
- o Characteristics of trough associated with East Coast cyclogenesis
 - A weak trough in the Ohio Valley appears to be responsible for the inverted surface trough, weak cyclone, and light precipitation amounts on 23 February. A second trough in the southwestern United States propagated eastward to the East Coast by 24 February, appeared to merge with the Ohio Valley trough, and influenced the more rapid development of the East Coast storm.
 - The presence of weak gradients and the large number and chaotic distribution of the troughs probably contributed to the slow movement of the entire storm system after it intensified on 25 February.
 - By 0000 GMT 25 February, the chaotic regime of small amplitude, high wavenumber cut-off features evolved into a simpler, organized lower wavenumber pattern with large amplitude features, including a major trough remaining off the West Coast, a ridge across the central United States and Canada, and a trough along the East Coast, which reflects the development of the surface cyclone along the coast at this time.
 - The trough axis became more negatively tilted and weakly diffluent (northeast of the axis) by 0000 GMT 25 February as the surface low went through its most rapid development phase with heavy snow across eastern New England.
 - The passage of a second trough across the southeastern United States on 24-25 February was followed by an increase in overall amplitude as a long wave trough/ridge pattern and a possible blocking situation became established over the United States. The establishment of a larger amplitude wave regime was associated with the slow movement of the storm off the coast for the following 3 to 4 days.
 - The half-wavelength is difficult to discuss due to the presence of many trough/ridge systems. However, the half-wavelength between the trough and adjacent ridges appears to increase as the long wave pattern emerges on 25 February, in contrast to other cases in which the wavelength tends to decrease.

Upper-level jet characteristics

- o The jet streak characteristics of the cyclone-associated troughs and flanking ridges
 - While the 500 mb geopotential fields were chaotic, especially prior to cyclogenesis, clearly defined upper-level jet streaks extended from northern Mexico to the Southeast Coast and marks the region of stronger height gradients along the periphery of the chaotic trough pattern.
 - Wind speeds were a maximum at both 200 and 300 mb and generally exceeded 80 m s^{-1} at the level of maximum winds for the entire observing period.
- o Other jet characteristics
 - A weak jet at 300 mb was located in the confluent region to the south of a small cut-off low over eastern Canada between 0000 GMT 23 and 24 February and may have influenced the large surface anticyclone across eastern Canada.

500 MB HEIGHTS AND UPPER-LEVEL WINDS



500 MB HEIGHTS (CONT.)

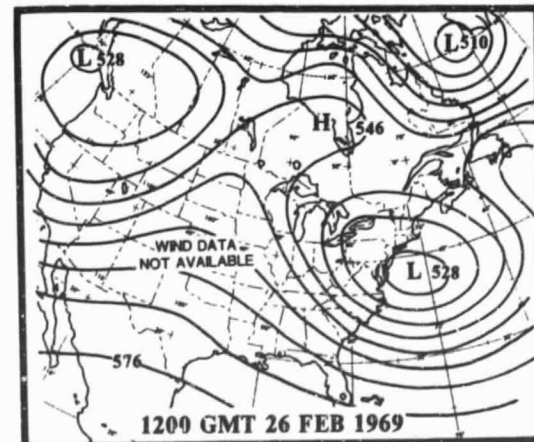
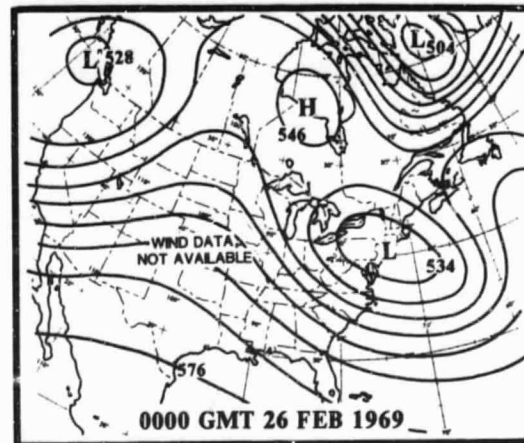
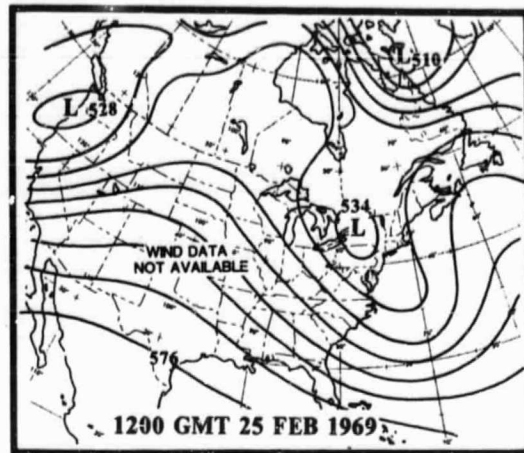


Fig. 44. The 500 mb geopotential height analyses and isotachs of maximum (cont.) wind speeds for 1200 GMT 25 February, 0000 GMT 26 February, and 1200 GMT 26 February 1969. See Fig. 4 caption for details.

25-28 December 1969

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21. 25-28 DECEMBER 1969

o General Remarks

- This storm was a near-miss for the large cities of the northeastern United States as heavy snow turned to rain (and back to snow in the New York City area), with heaviest snow immediately north and west of the coastal plain. The storm is considered one of the heaviest snowstorms on record for eastern and northern New York. Accumulations of greater than twenty (>50 cm) covered a wide region of central and eastern New York into northern New England.

o Regions with snow accumulations exceeding 10 in (25 cm)

- western Virginia, western Maryland, portions of West Virginia, central and eastern Pennsylvania (except the extreme southeast), central and eastern New York (except the coast), Connecticut (except the coast), central and western Massachusetts, Vermont, New Hampshire, and western Maine

o Regions with snow accumulations exceeding 20 in (51 cm)

- northeastern Pennsylvania, much of eastern New York, and Vermont

o Urban center snowfall amounts:

Washington, D.C.-Reagan Airport	12.1" (31 cm)
Baltimore, Md.	6.1" (15 cm)
Philadelphia, Pa.	5.2" (13 cm)
New York, N.Y.-La Guardia	7.4" (19 cm)
Boston, Ma.	4.2" (11 cm)

o Other selected snowfall amounts:

Burlington, Vt.	29.8" (76 cm)
Albany, N.Y.	26.4" (67 cm)
Binghamton, N.Y.	21.9" (56 cm)
Williamsport, Pa.	17.2" (44 cm)
Roanoke, Va.	16.4" (42 cm)
Hartford, Ct.	15.1" (39 cm)
Harrisburg, Pa.	13.9" (33 cm)

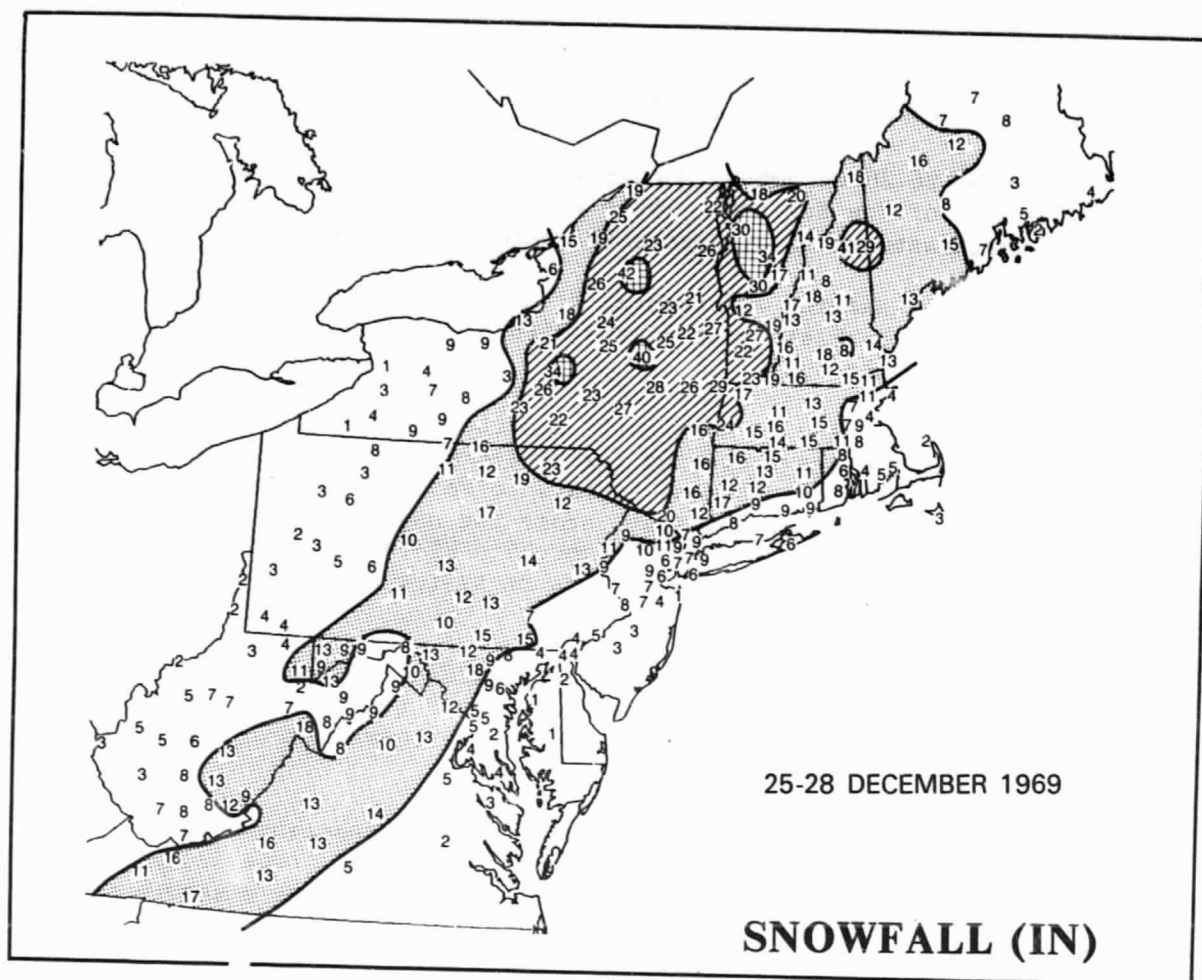


Fig. 45. Total snow accumulations for 25 to 28 December 1969 (in). See Fig. 1 caption for details.

Surface characteristics

- o Type "A" (Miller, 1946)
- o Prior to 26 December, a cold anticyclone (1033 mb) was centered north of New England. The high center drifted slowly northeastward as cyclogenesis commenced on the coast.
- o Cold air damming and coastal frontogenesis were prominent along much of the East Coast on the 25th and along the New England coast on the 26th.
- o The surface low is marginally ascribed as type "A" (Miller, 1946) since there are two low pressure systems on 25 December. However, the development appears to resemble a type "A" storm since the surface low that became the major coastal storm appears to develop over the southern Plains and Gulf Coast independently of a weakening storm system near the Canadian border.
- o By 1200 GMT 26 December, the main surface low crossed the Gulf states and moved up the East Coast with precipitation spreading rapidly toward the Northeast and heavy snow falling along the Appalachian Mountains.
- o The storm track's close proximity to the coastline resulted in snow changing to rain along the coastal areas, especially in New England. Central New England was also plagued by a severe ice storm.
- o After the surface low moved rapidly up the coast between 0000 GMT and 1200 GMT 26 December, it slowed considerably as it reached the New Jersey shore. It then moved very slowly along the New England coast for the following 24 to 36 hours, averaging 5 to 10 m s⁻¹.
- o Deepening occurred during two periods. The first period of rapid deepening occurred between 0000 GMT 26 December and 1200 GMT 26 December, in which the storm's central pressure fell 12 mb in 12 h as the storm moved from Georgia to New Jersey. During this period, heavy precipitation spread quickly across the Middle Atlantic states into New England. The following 12 h were marked by little, if any, deepening and slow movement from New Jersey to just east of Long Island. The period between 0000 GMT and 1200 GMT 27 December brought the second period of rapid deepening as the central pressure fell another 12 mb to 976 mb as the cyclone drifted to the Massachusetts coast. It was also during this period that "backlash" snowfall occurred over New York City and Long Island, dropping as much as an additional 6 in (15 cm) on the area. The following 24 h saw the cyclone continue to drift slowly east-northeastward.

- o The slow movement of the storm center after 1200 GMT 26 December contributed to the very heavy snowfall in northern New York and Vermont and also resulted in considerable warming over northern and eastern New England. The warming from the Atlantic and cold air remaining over western New England created a strong frontal boundary across central New England (not analyzed by NMC), similar to that observed during the "Blizzard of '88" (Kocin, 1983).

SURFACE

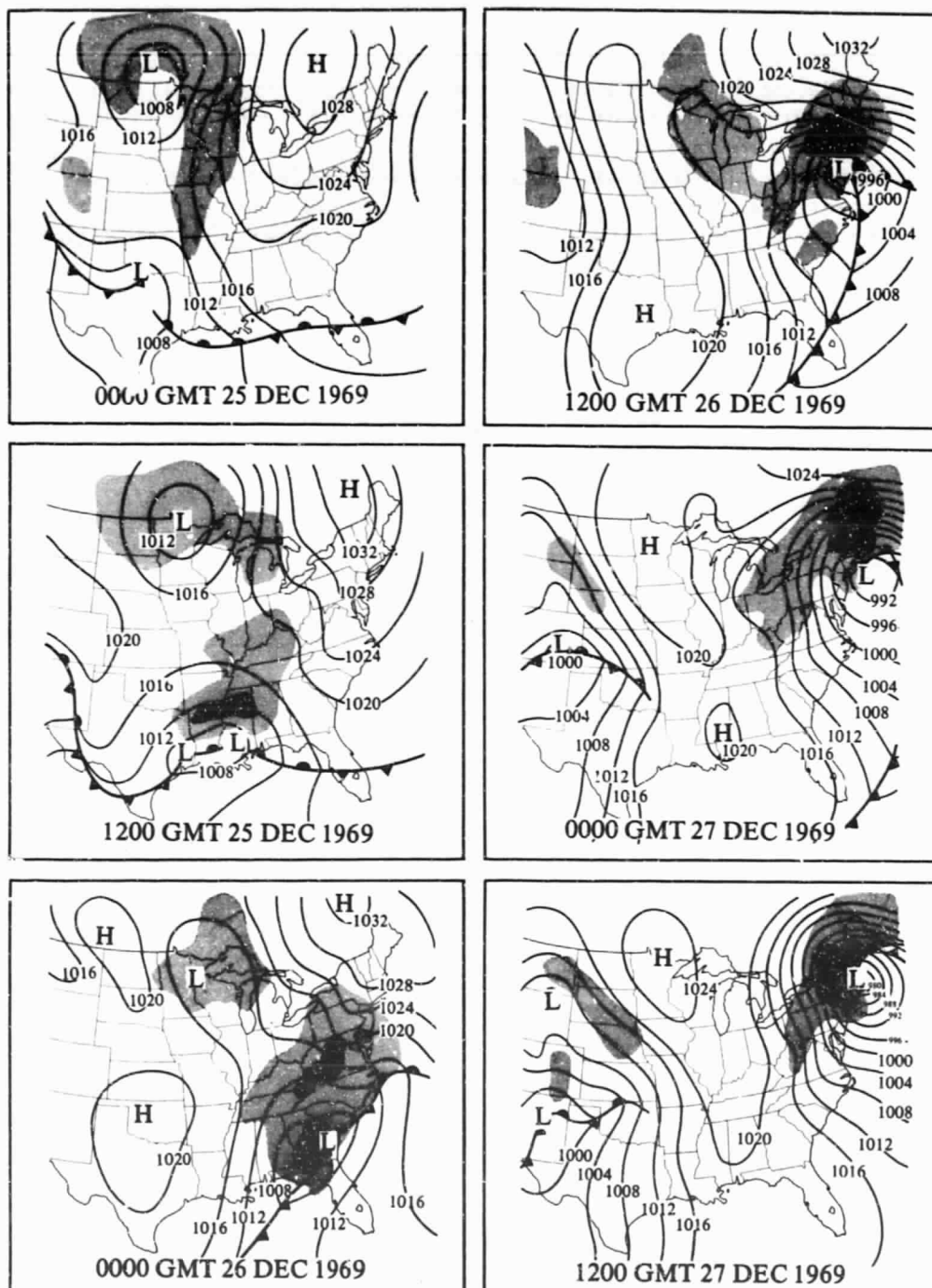


Fig. 46. Surface frontal and weather analyses for 0000 GMT 25 December, 1200 GMT 25 December, 0000 GMT 26 December, 1200 GMT 26 December, 0000 GMT 27 December, and 1200 GMT 27 December 1969. See Fig. 2 caption for details.

850 mb characteristics

- o Weak northwesterly flow and cold advection across the northeastern United States on 24 December preceded this snowstorm.
- o Two separate 850 mb low centers were observed prior to East Coast cyclogenesis.
 - The first low center drifted slowly southeastward from the Northern Plains to the Upper Great Lakes on 25 to 26 December. This low was initially associated with a strong temperature gradient at 1200 GMT 25 December that weakened by 1200 GMT 26 December as the low filled.
 - The second center, which was associated with the major storm, drifted eastward across the south-central to southeastern United States along a strong temperature gradient that was separate from the other center over the northern United States (providing more support for a type "A" storm).
- o The second low center deepened very slowly on 25 December and then went through two 12 h periods of rapid deepening (as did the surface low). The first period occurred between 0000 GMT and 1200 GMT 26 December ($-90 \text{ m (12 h)}^{-1}$) and the second period between 0000 GMT and 1200 GMT 27 December ($-90 \text{ m (12 h)}^{-1}$).
- o The low remained near the 0°C isotherm throughout the study period.
- o A pronounced "S"-shaped isotherm pattern emerged by 0000 GMT 26 December as cyclogenesis was underway along the Atlantic coast. A north-south isotherm pattern across New England evolved on 27 December as the low moved very slowly into southern New England with warm air rushing into eastern New England changing the snow to rain.
- o The temperature gradient increased across southern New England by 0000 GMT 26 December as the first period of rapid deepening occurred.
- o A strong southerly jet developed across the southeastern United States at 1200 GMT 25 and 0000 GMT 26 December, immediately prior to the first period of rapid deepening along the Atlantic coast. Coastal frontogenesis and precipitation were developing along the Southeast coast at these times. The jet formed as the rapid eastward movement of the 850 mb low (which was beginning to deepen) encountered a slower-propagating ridge to its east, with a corresponding increase of the geopotential gradients along the Southeast coast.
- o An easterly jet to the north of the low developed by 1200 GMT 26 December as the cyclone was undergoing its first period of rapid deepening. It appears that both these low-level jet flows contributed to enhanced moisture transports into regions of heavy precipitation.

850 MB

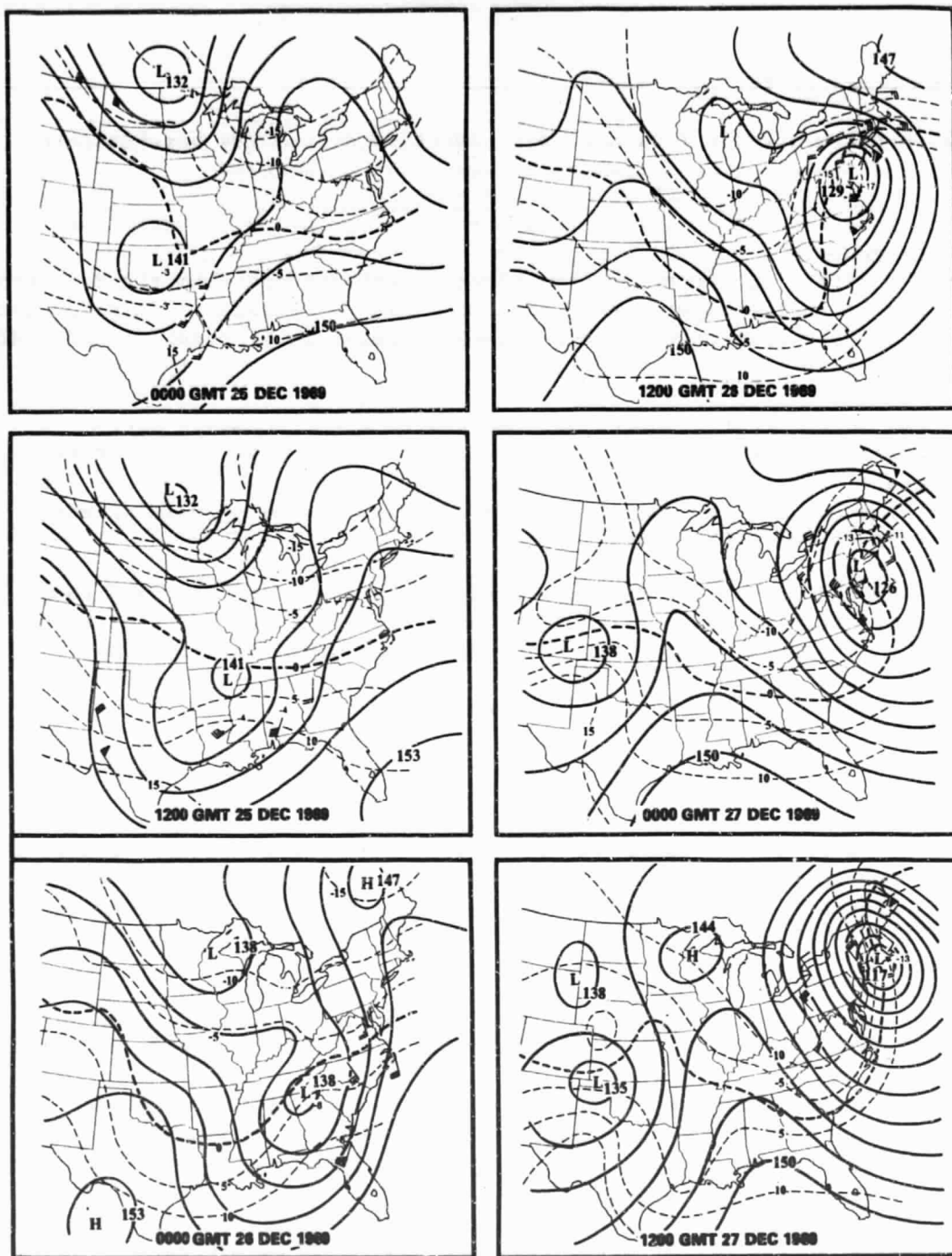


Fig. 47. The 850 mb analyses for 0000 GMT 25 December, 1200 GMT 25 December, 0000 GMT 26 December, 1200 GMT 26 December, 0000 GMT 27 December, and 1200 GMT 27 December 1969. See Fig. 3 caption for details.

500 mb geopotential height characteristics

- o General features prior to cyclogenesis along the East Coast
 - The pre-cyclogenetic period was marked by almost zonal flow across much of the United States with no high amplitude features across either the United States or Canada. A trough over eastern Canada is not as well-defined as in other cases. The flow over New England and the Great Lakes also is not marked by the degree of confluence as in the precyclogenetic periods of other cases. Some confluence is seen across the Middle Atlantic states into New England between 0000 GMT 25 and 26 December. The lack of a persistent field of confluence may have contributed to the inability of the cold anticyclone to become firmly established over the Middle Atlantic states and thus, prevent a changeover to rain that occurred along the coast.
- o Characteristics of trough associated with East Coast cyclogenesis
 - The cyclone's development was characterized by the amplification of a long wave trough over the central United States after 0000 GMT 25 December as the low pressure system was developing along the Gulf Coast. A closed center formed at 500 mb by 1200 GMT 27 December.
 - By 1200 GMT 26 December, the 500 mb trough continued to deepen rapidly over the southeastern United States and attained a noticeable negative tilt with little diffluence as the surface low moved rapidly toward New England and went through its first deepening phase. Geopotential gradients at the base of the trough also increased by this time.
 - The deepening trough seemed to pivot about the slower-moving northern trough located over the Great Lakes region at 1200 GMT 26 December. This slow-moving trough is associated with the dying surface system over the northern United States.
 - The cyclogenetic period from 26 to 27 December was characterized by an increase in amplitude of the long wave features. The amplitude of trough and upstream ridge over the western United States increased slightly before a large increase in amplitude occurred between the trough nearing the eastern United States and the downstream ridge over New England and southeastern Canada on 26 December.
 - The half-wavelength of the trough and downstream ridge appeared to shorten during cyclogenesis, especially between 0000 GMT 26 and 0000 GMT 27 December.
 - By 1200 GMT 27 December, the trough became more negatively tilted with pronounced diffluence over New England between the trough and the downstream ridge. This coincided with the second period of rapid deepening as the surface low moved very slowly along the New England coast.

Upper-level jet characteristics

- o Unlike nearly all other cases, the jet maxima were located in the₁ ridge crest upstream of the trough with winds in excess of 70 m s^{-1} (maximized at 300 mb) throughout the entire study period.
- o There are some indications that a separate jet streak propagated toward the base of the trough by 1200 GMT 26 December as the amplitude of the trough increased. However, by this time, the surface low was already located over southern New Jersey, well to the north of this jet streak.
- o The initial development phase and rapid northeast propagation of the surface low after 0000 GMT 26 December seems to occur in the entrance region of a jet streak in the downstream ridge over New England. This jet amplified from 60 to 70 m s^{-1} between 0000 GMT 26 December 1969 and 0000 GMT 27 December 1969 as heavy precipitation spread rapidly up the East Coast. The development of precipitation across the eastern United States occurred primarily to the anticyclonic side of the entrance region of this jet, where ascent is expected to occur (see Part 1).

500 MB HEIGHTS AND UPPER-LEVEL WINDS

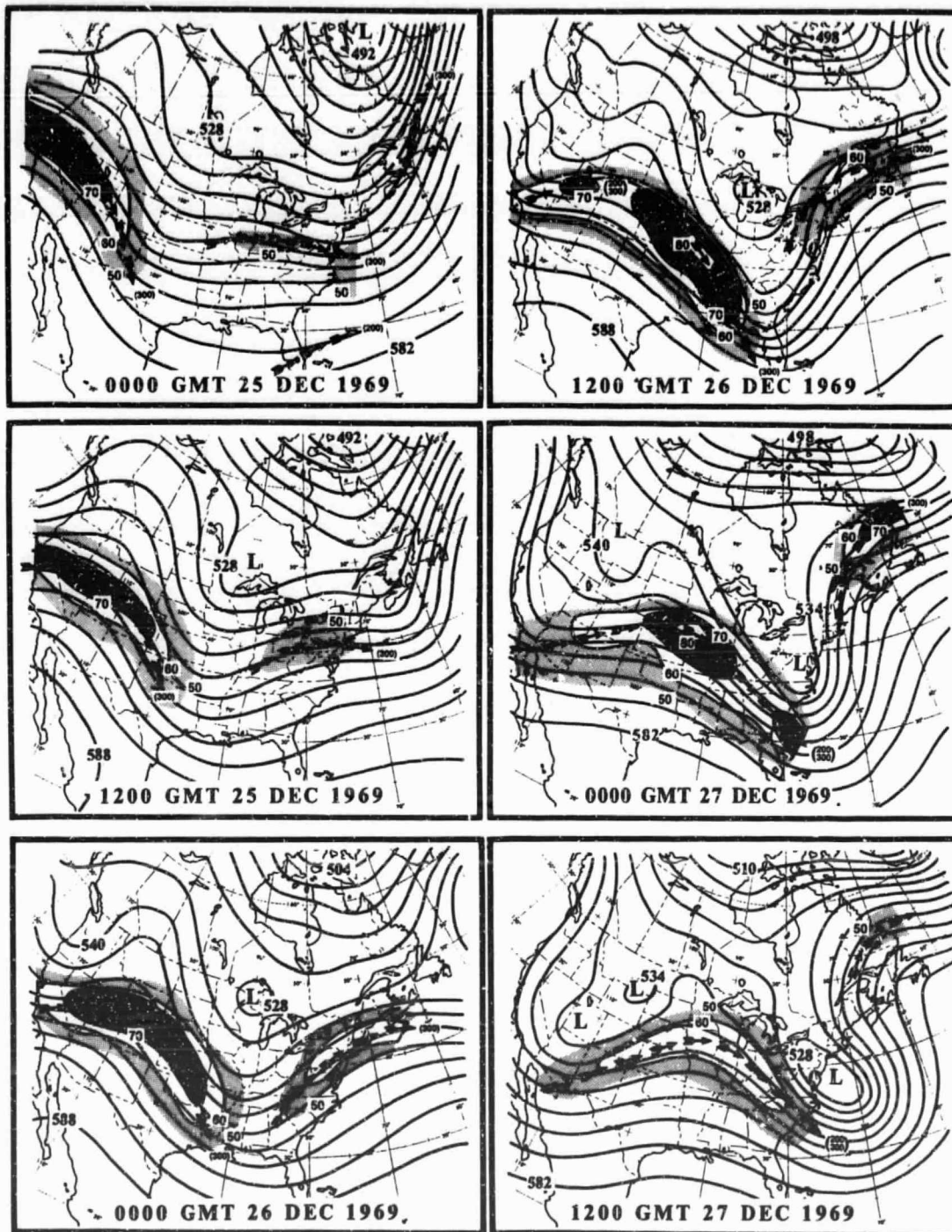


Fig. 48. The 500 mb geopotential height analyses and isotachs of maximum wind speeds for 0000 GMT 25 December, 1200 GMT 25 December, 0000 GMT 26 December, 1200 GMT 26 December, 0000 GMT 27 December, and 1200 GMT 27 December 1969. See Fig. 4 caption for details.

18-20 February 1972

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o General Remarks

- This storm was another near-miss for the major cities as heaviest snowfall was located immediately to their west and north. The storm was one of few storms during the early and middle 1970's which posed a threat of heavy snow in the Northeast urban corridor. Strong easterly winds and rough seas caused significant damage along the Middle Atlantic and New England coasts.

o Regions with snow accumulations exceeding 10 in (25 cm)

- eastern West Virginia, northern Virginia, central and northern Maryland, Pennsylvania (except the west and southeast), northwestern New Jersey, New York (except the extreme west and coastal regions), central and northern Connecticut, Massachusetts (except the southeast), Maine, and parts of New Hampshire and Vermont

o Regions with snow accumulations exceeding 20 in (51 cm)

- north-central Pennsylvania, parts of central New York and West Virginia

o Urban center snowfall amounts:

Washington, D.C.-Dulles Airport	10.0" (25 cm)
Baltimore, Md.	3.2" (8 cm)
Philadelphia, Pa.	3.7" (9 cm)
New York, N.Y.-La Guardia	6.3" (16 cm)
Boston, Ma.	6.3" (16 cm)

o Other selected snowfall amounts:

Binghamton, N.Y.	24.4" (62 cm)
Williamsport, Pa.	22.8" (58 cm)
Syracuse, N.Y.	20.0" (51 cm)
Portland, Me.	15.4" (39 cm)
Worcester, Ma.	15.2" (39 cm)
Harrisburg, Pa.	13.0" (33 cm)
Albany, N.Y.	12.1" (31 cm)

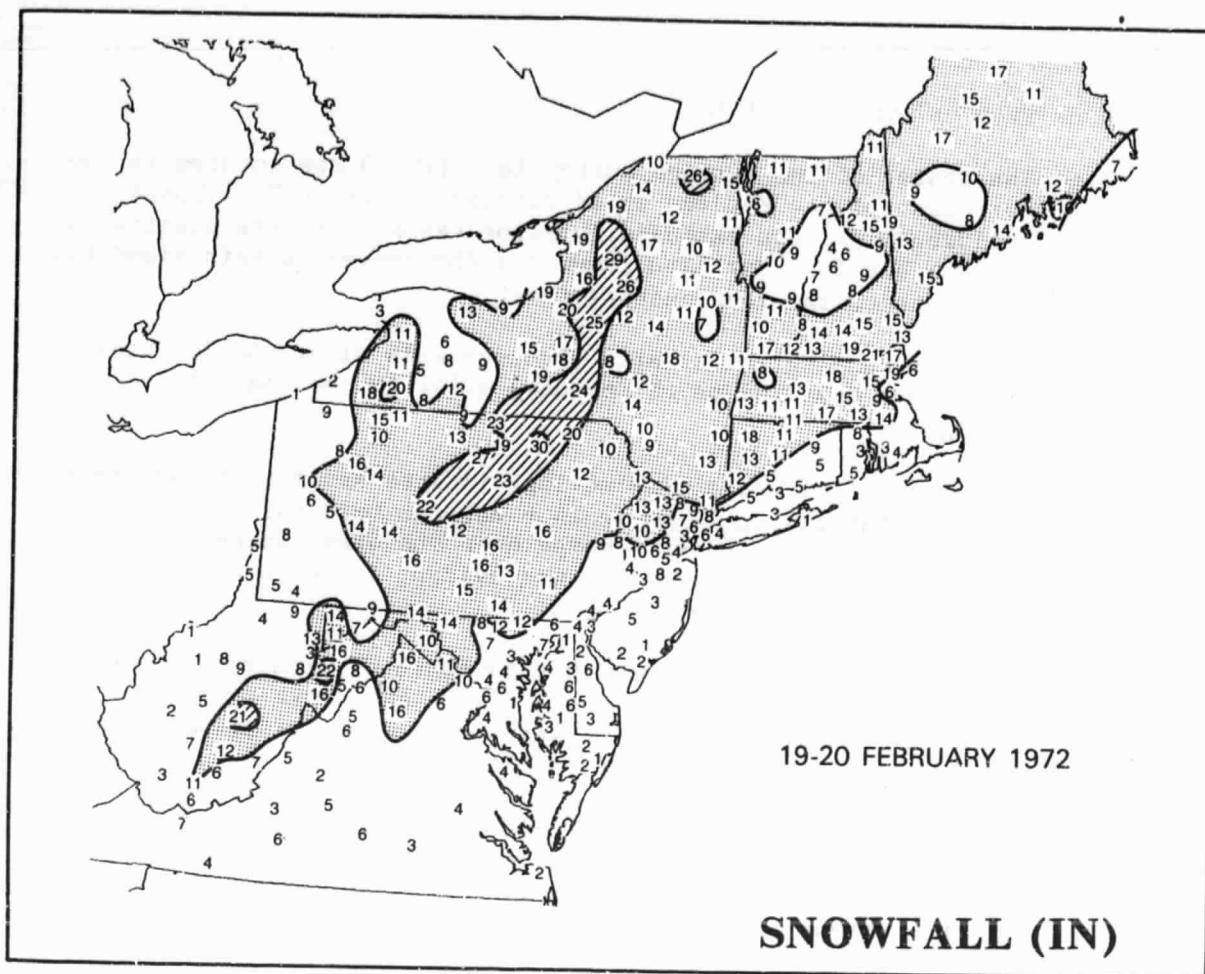


Fig. 49. Total snow accumulations for 19 to 20 February 1972 (in). See Fig. 1 caption for details.

Surface characteristics

- o Type "B" (Miller, 1946)
- o The center of the surface anticyclone (1035) was located to the northeast of New England on 18 February prior to East Coast cyclogenesis. Its eastward location (as well as the position of the surface low) may have insured a changeover to rain along the coast due to the long onshore flow.
- o Cold air damming and coastal frontogenesis along the Southeast coast were observed on 18 February prior to the coastal cyclogenesis.
- o The primary low was a slow-moving, intense storm over the upper Midwest that filled 10 mb in 24 h between 0000 GMT 18 and 0000 GMT 19 February as it moved over the Great Lakes. Nevertheless, the primary low was evident for 27 h after the onset of secondary cyclogenesis.
- o The secondary low developed 1600 km south of primary low over southern Georgia and Alabama at 1200 18 February. The separation represents the largest displacement of primary and secondary low centers of the sample.
- o The secondary low moved northeastward immediately along the coast, propagating at 15 to 20 m s⁻¹ along the Southeast coast. The forward motion slowed over the Middle Atlantic and New England shores. By midday 18 February, the cyclone developed dual centers as it moved erratically and slowly off the New Jersey and New England coasts.
- o A wind shift associated with an inverted trough north of the secondary low may have been instrumental in heavy snowfall in Pennsylvania, Maryland, and Virginia on 19 February.
- o Explosive deepening of the secondary low occurred after 0300 GMT 19 February as the low deepened 25 mb in 12 hours to 975 mb over New Jersey at 1500 GMT 19 February.
- o An intense pressure gradient developed to the northeast of the rapidly developing storm on 19 February, was associated with very strong winds, and provided for a strong easterly fetch of air toward the New Jersey and Long Island shorelines. However, true blizzard conditions did not occur since temperatures were above 20°F (-7°C) in the regions reporting snow.

SURFACE

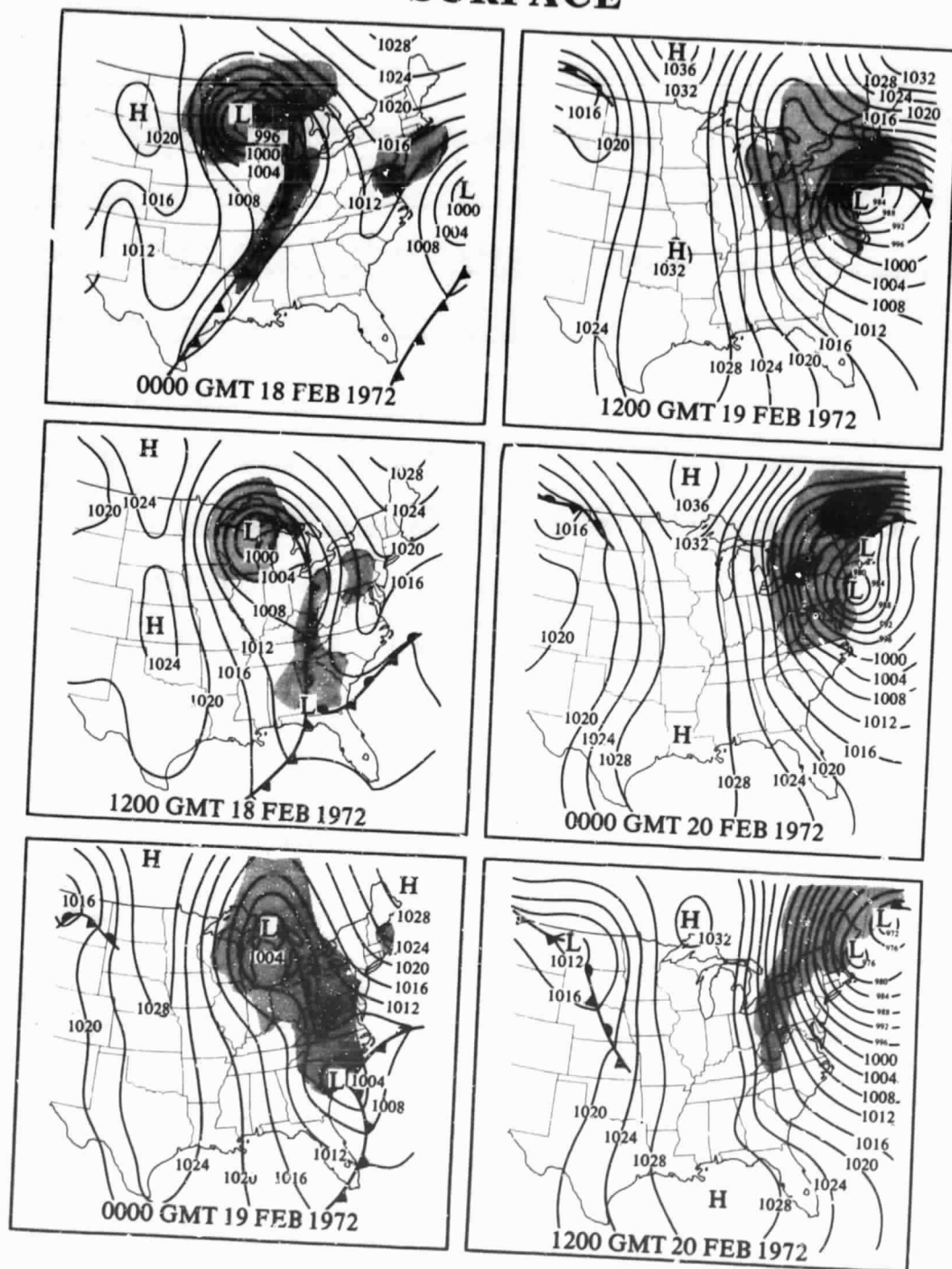


Fig. 50. Surface frontal and weather analyses for 0000 GMT 18 February, 1200 GMT 18 February, 0000 GMT 19 February, 1200 GMT 19 February, 0000 GMT 20 February, and 1200 GMT 20 February 1972. See Fig. 2 caption for details.

850 mb characteristics

- o The pre-cyclogenetic period on the East Coast was not characterized by northwesterly flow and cold advection over the Great Lakes and New England.
- o An intense 850 mb low center remained relatively stationary across the upper Great Lakes through 0000 GMT 19 February. It was located well to the north of the 0°C isotherm and weakened rapidly in the 24 h period after 1200 GMT 18 February as the 0°C isotherm progressed further away from the low center.
- o The circular low center over the upper Great Lakes elongated on a north-south axis by 0000 GMT 19 February with a new center developing across the southeastern states near the 0°C isotherm. The low center could not be analyzed by 1200 GMT 19 February as a secondary 850 mb circulation intensified rapidly along the East Coast.
- o The secondary low intensified explosively in the 24 h period following 0000 GMT 19 February, deepening 150 m in the 12 h period ending at 1200 GMT 19 February and 90 m in the following 12 h period ending at 0000 GMT 20 February.
- o The secondary development occurred concurrently as an "S"-shaped isotherm pattern took shape along the East Coast. The temperature gradient intensified along the East Coast by 1200 GMT 19 February following the appearance of the "S"-shaped isotherm pattern and during the cyclone's most rapid intensification.
- o The 0°C isotherm was located near the secondary low center during this period of rapid deepening, with the low becoming located in colder air as it occluded on 20 February.
- o A strong northerly jet to the west of the low centers characterized the pre-secondary cyclogenesis period on 18 February, accompanied by cold advection.
- o An intense easterly jet formed to the north of the rapidly deepening coastal low by 1200 GMT 19 February, directed towards and coinciding with the outbreak of heavy snow and rainfall in the Middle Atlantic states and New England. This suggests that the increasing moisture flux associated with the intensifying low-level flow field was an important factor in the expanding area of heavy precipitation on 19 February.

850 MB

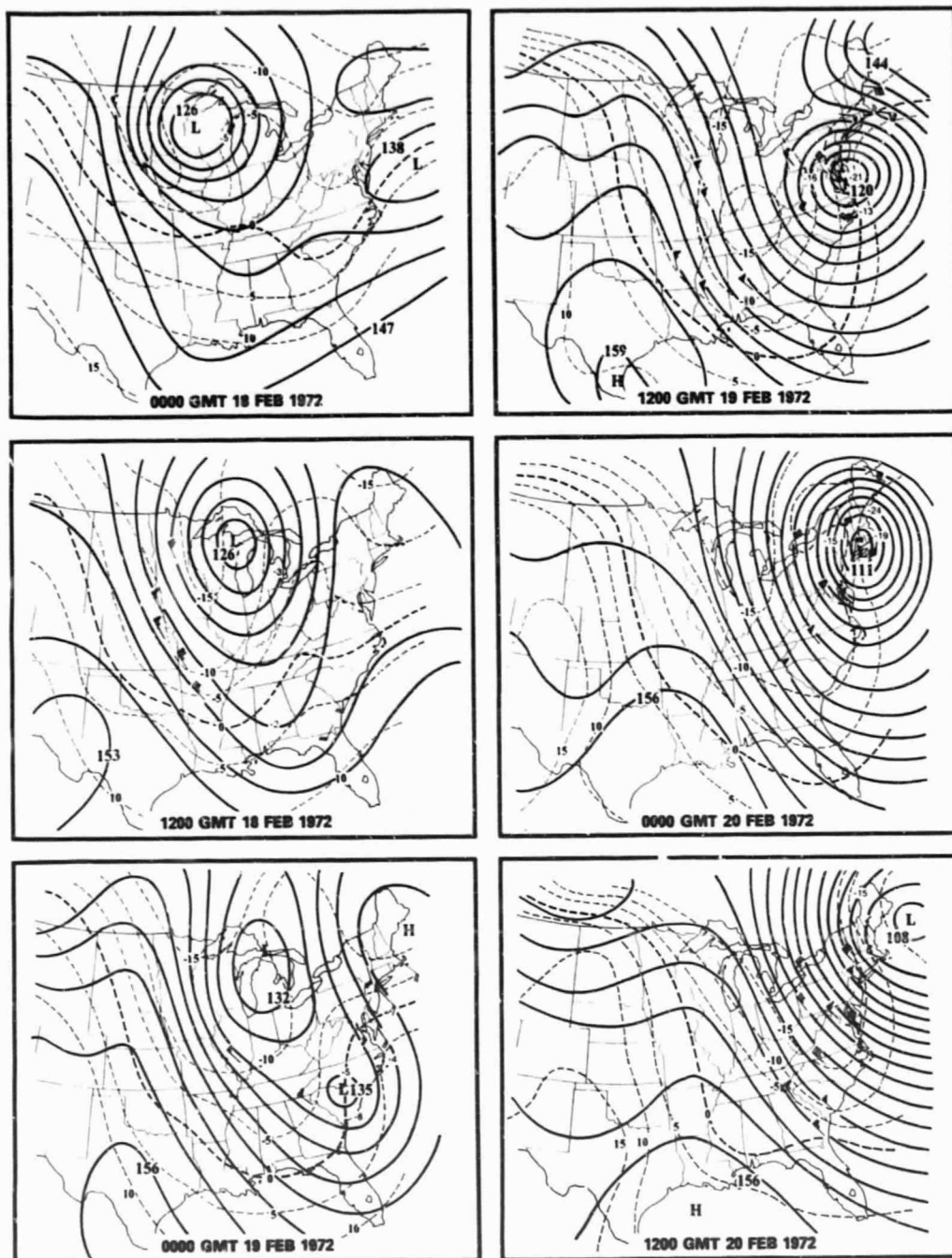


Fig. 51. The 850 mb analyses for 0000 GMT 18 February, 1200 GMT 18 February, 0000 GMT 19 February, 1200 GMT 19 February, 0000 GMT 20 February, and 1200 GMT 20 February 1972. See Fig. 3 caption for details.

500 mb geopotential height characteristics

- o General features prior to cyclogenesis along the East Coast
 - A trough over eastern Canada was associated with confluence across southeastern Canada. The location of the confluent zone was further east and north than in many of the other cases as it lifted northeastward toward Greenland during 18 and 19 February. In addition, a slowly amplifying ridge was established over the western United States on 18 February as a long wave trough amplified across the central and eastern United States prior to and during the East Coast cyclogenesis.
- o Characteristics of trough associated with East Coast cyclogenesis
 - The trough over the central United States continued to amplify through 1200 GMT 19 February as it drifted toward the East Coast.
 - A height minimum at 500 mb over the Great Lakes between 0000 GMT 18 and 19 February was nearly colocated with the location of the weakening primary surface low. This height minimum disappeared by 1200 GMT 19 February as a new and rapidly deepening closed low center formed across the eastern United States during the explosive secondary cyclogenesis along the Middle Atlantic coast. The closed center "opened up" by 1200 GMT 20 February after the cyclone had occluded. The upper-level trough became negatively tilted by 0000 GMT 19 February as the surface low began to develop off the South Carolina coast.
 - Geopotential gradients at the base of the trough increased at 0000 GMT 19 February, immediately prior to rapid secondary cyclogenesis.
 - By 1200 GMT 19 February, the amplitude of the trough and downstream ridge increased with noticeable diffluence developing east of the trough axis over the northeastern United States where heavy precipitation was observed immediately north and west of the rapidly deepening storm center.
 - There was a distinct shortening of half-wavelength between the trough and downstream ridge during rapid secondary development, especially between 0000 GMT 19 and 0000 GMT 20 February.

Upper-level jet characteristics

- o Jet streak characteristics of the cyclone-associated trough and flanking ridges
 - A jet streak was located over the southeastern United States prior to East Coast cyclogenesis on 0000 GMT 19 February, downstream of the trough axis over the central United States and upstream of a weaker short wave trough moving out over the Atlantic Ocean that was associated with a weak surface cyclone along the East Coast prior to 18 February.
 - Another jet streak propagated from the ridge position over the West Coast toward the base of the amplifying trough by 0000 GMT 19 February. This jet appears to expand in length as the geopotential

- height gradients increase over₁ the Gulf of Mexico on 19 February. Maximum wind speeds of 60 m s^{-1} are not as large as in other cases.
- Winds at the base of the trough are difficult to describe at the time of secondary cyclogenesis since strongest winds are located over data-void regions off the East and Gulf Coasts. However, at 1200 GMT 19 February, it appears that the exit region of the jet is near the diffluent region of the trough as the surface low was deepening rapidly off the Middle Atlantic coast and as heavy precipitation developed across the northeastern United States.

500 MB HEIGHTS AND UPPER-LEVEL WINDS

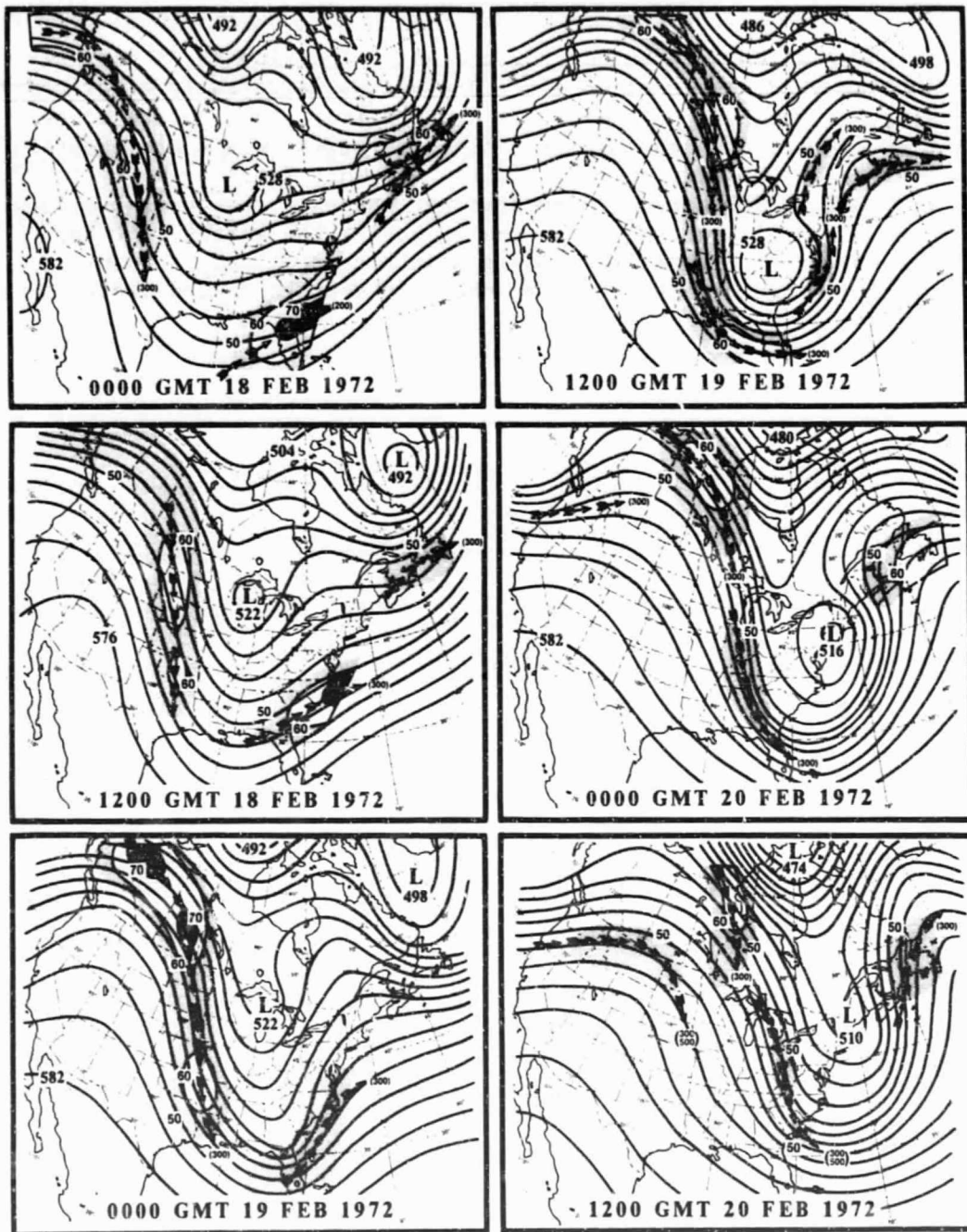


Fig. 52. The 500 mb geopotential height analyses and isotachs of maximum wind speeds for 0000 GMT 18 February, 1200 GMT 18 February, 0000 GMT 19 February, 1200 GMT 19 February, 0000 GMT 20 February, and 1200 GMT 20 February 1972. See Fig. 4 caption for details.

19-20 January 1978

2n. 19-20 JANUARY 1978

o General Remarks

- For much of the urban northeastern United States, this storm was the most severe snowstorm since 1969. The storm was the last in a series of three cyclones during a week that produced a variety of winter weather conditions across the Northeast. Along the coast, snowfall was underforecast since a predicted changeover from snow to rain either did not occur or occurred after there had been substantial accumulations. The 1000 to 500 mb geopotential thicknesses were unusually high for this case to support snowfall. A large variation in snowfall amounts is noted along the axis of heavy snowfall extending from West Virginia into Pennsylvania, northern New Jersey, New York, and New England. Boston, Ma. set its 24 h snowfall record with this storm, only to have it broken two weeks later. The storm was accompanied by wind gusts exceeding 20 m s⁻¹ from New Jersey to the New England coast.

o Regions with snow accumulations exceeding 10 in (25 cm)

- sections of West Virginia, western and northern Virginia and Maryland, much of Pennsylvania, central and northern New Jersey, much of New York and New England

o Regions with snow accumulations exceeding 20 in (51 cm)

- portions of West Virginia, western Maryland, central and northeastern New York, eastern Massachusetts, and sections of Rhode Island

o Urban center snowfall amounts:

Washington, D.C.-Dulles Airport	7.5" (19 cm)
Baltimore, Md.	5.6" (14 cm)
Philadelphia, Pa.	13.2" (34 cm)
New York, N.Y.-Kennedy Airport	14.2" (36 cm)
Boston, Ma.	21.5" (54 cm)

o Other selected snowfall amounts:

Syracuse, N.Y.	18.9" (48 cm)
Charleston, W.V.	18.4" (47 cm)
Newark, N.J.	17.8" (45 cm)
Bridgeport, Ct.	16.7" (42 cm)
Hartford, Ct.	15.5" (39 cm)
Pittsburgh, Pa.	14.0" (36 cm)

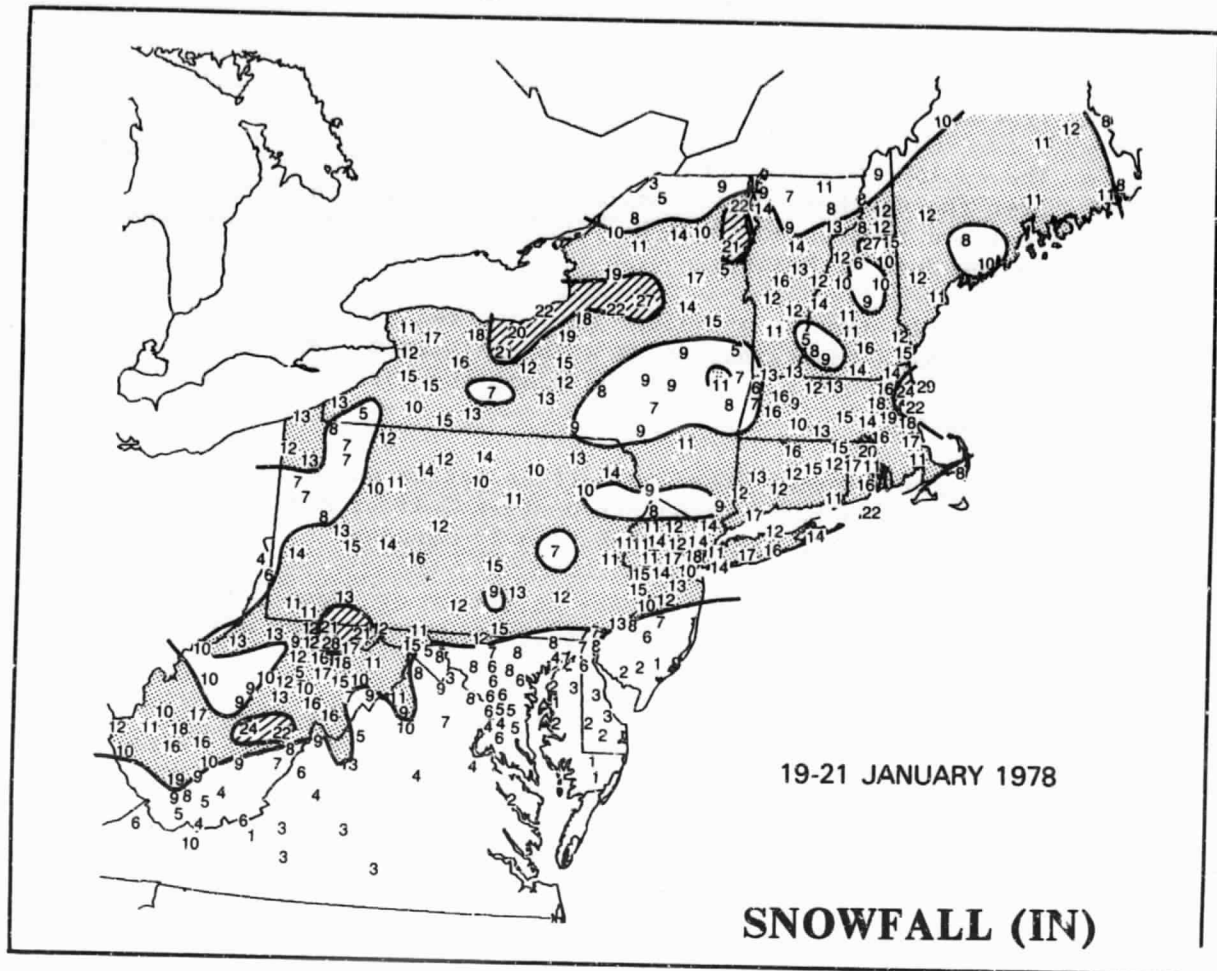


Fig. 53. Total snow accumulations for 19 to 21 January 1978 (in). See Fig. 1 caption for details.

Surface characteristics

- o Type "A" (Miller, 1946)
- o The cyclone was preceded by a large cold anticyclone (1046 mb) over the northern Plains states on 19 January that built eastward towards northern New England as the cyclone developed in the Gulf of Mexico.
- o Noticeable damming of colder air occurred east of the Appalachian Mountains, along with a distinct coastal front and inverted trough that developed along the Carolina coast on 19 January.
- o The cyclone formed over the Gulf of Mexico on 18 January and moved northeastward along the eastern Gulf of Mexico before passing up along the East Coast on 20 January.
- o The surface low had a tendency to reform or "jump" along the coastal front off the Southeast coast between 0000 GMT and 1200 GMT 20 January.
- o This storm underwent a history of rather erratic intensification. After forming in the Gulf of Mexico, the central pressure of the cyclone vacillated as it propagated northeastward. It deepened rapidly for only a brief period of time off the New Jersey coast near 1800 GMT 20 January, during which time the storm reached its lowest pressure of 995 mb.
- o Although the cyclone was not very deep, the areal extent of its circulation pattern and interaction with an intense Canadian anticyclone produced a widespread snowstorm accompanied by gale-force winds along the Atlantic coast. Winds increased along the Middle Atlantic coast on 20 January as the distance between the advancing surface low and relatively stationary anticyclone decreased.
- o The heaviest precipitation fell along and to the west of the coastal front, especially at 0000 GMT 20 January, far to the northeast of the surface low pressure center.

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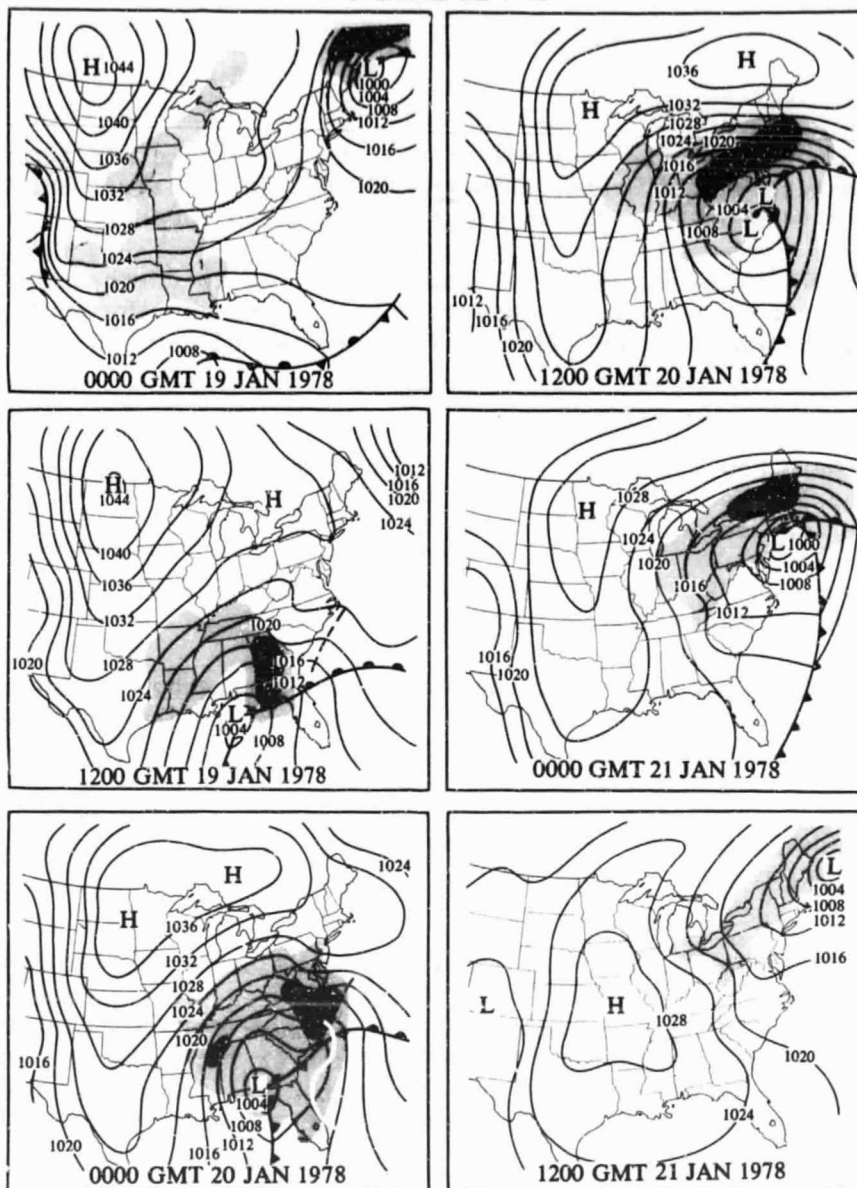


Fig. 54. Surface frontal and weather analyses for 0000 GMT 19 January, 1200 GMT 19 January, 0000 GMT 20 January, 1200 GMT 20 January, 0000 GMT 21 January, and 1200 GMT 21 January 1978. See Fig. 2 caption for details.

850 mb characteristics

- o West to northwesterly flow maintained low-level cold air across the northeastern United States through 0000 GMT 20 January. This flow was located beneath a region of upper-level confluence.
- o The 850 mb low developed in a broad, south-east to northeast aligned baroclinic zone across the eastern United States on 18 January. The cyclonic circulation expanded on 19 February and covered much of the eastern United States by 20 January.
- o The 850 mb low deepened slowly as it propagated from the Texas coast to southern New England. The greatest deepening ($-60 \text{ m (12 h)}^{-1}$) occurred between 1200 GMT 19 and 0000 GMT 20 January although the surface low deepened only slightly.
- o No pronounced "S"-shaped isotherm pattern developed as the storm moved up the East Coast.
- o The 850 mb temperature gradient downstream of the 850 mb low increased in magnitude, especially by 1200 GMT 19 January from Virginia and New England, as heavy snow spread across the Middle Atlantic states and southern New England.
- o The low developed to the warm side of the 0°C isotherm on 18 January and became oriented closer to the 0°C isotherm by the time it reached Virginia.
- o A southerly low-level jet developed across Florida by 0000 GMT 19 January and was located immediately downwind of an outbreak of moderate precipitation across the southeastern United States. Easterly winds to the north of the low center increased in speed as the low intensified and moved up the East Coast between 1200 GMT 19 January and 1200 GMT 20 January.

850 MB

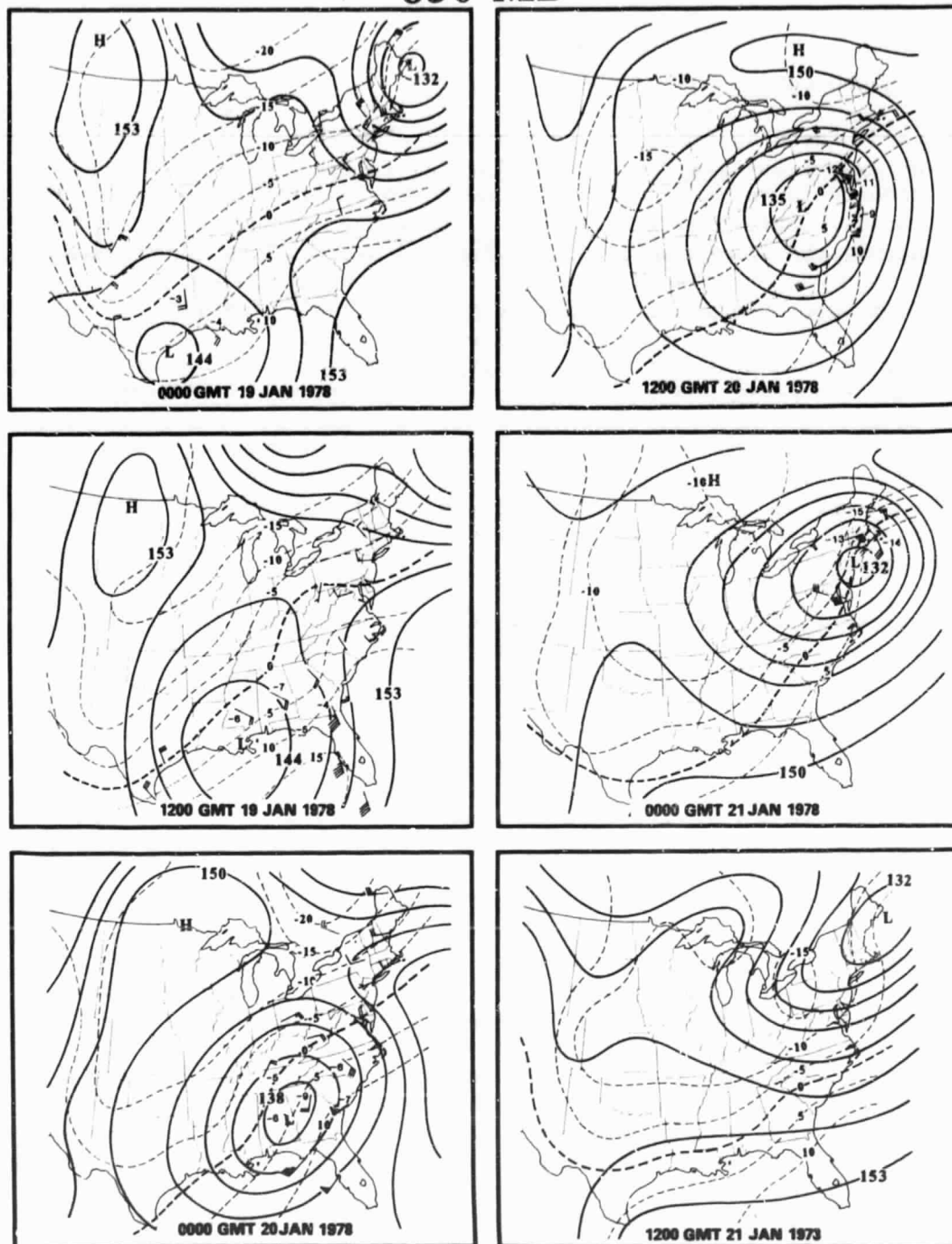


Fig. 55. The 850 mb analyses for 0000 GMT 19 January, 1200 GMT 19 January, 0000 GMT 20 January, 1200 GMT 20 January, 0000 GMT 21 January, and 1200 GMT 21 January 1978. See Fig. 3 caption for details.

500 mb geopotential height characteristics

- o General features prior to cyclogenesis along the East Coast
 - While the surface cyclone was forming in the Gulf of Mexico on 18 January, a cut-off vortex over northern Quebec was surrounded by large geopotential gradients and short wave troughs that extended across the Great Lakes and New England states. One short wave trough was associated with another cyclone that had moved off the East Coast and was located over Newfoundland by 1200 GMT 19 January. The trough was followed by significant ridging over the western Atlantic on 19 January. The amplification of the ridge near the coast and the maintenance of the trough over eastern Canada resulted in a strongly confluent upper-level geopotential region near the United States-Canadian border between 1200 GMT 19 January and 1200 GMT 20 January. This feature was observed as the surface anticyclone built eastward across New York and New England and as cold air damming developed to the east of the Appalachian Mountains.
- o Characteristics of trough associated with East Coast cyclogenesis
 - The trough that produced the storm was a "digging" low-latitude system that propagated across the southern United States on 18 and 19 February.
 - A trough with weak geopotential gradients formed across the Midwest by 0000 GMT 20 January. The trough which spawned the East Coast cyclone crossed the southern United States on 18 and 19 January and pivoted in a counterclockwise sense around the Midwest trough up the East Coast on 20 January. The trough did not evolve into a closed center at 500 mb.
 - Although the trough was "digging" toward the Gulf coast prior to 1200 GMT 19 January, the amplitude of the trough and upstream ridge over the western United States did not appear to significantly increase prior to cyclogenesis at 1200 GMT 19 January as both trough and upstream ridge axes appear to be moving southward.
 - An inferred geostrophic vorticity maximum at the base of the trough was located further south than in any other case.
 - The trough axis became negatively tilted by 1200 GMT 20 January, but the flow does not appear to become diffluent east of the trough axis, as it did in many other cases. The surface low only deepened by 4 mb in the 24 h period between 1200 GMT 20 and 1200 GMT 21 January, when the heaviest snow fell across the northeastern United States. The lack of strong diffluence may be associated with the small surface deepening rate observed in this case.
 - The amplitude of the trough and downstream ridge along the Atlantic coast increased significantly from 0000 GMT 19 January to 0000 GMT 20 January as the cyclone developed along the Gulf Coast and as the coastal front formed along the Carolina coast.
 - The half-wavelength between the trough and downstream ridge decreased between 0000 GMT 20 January and 1200 GMT 20 January as the surface pressure gradients increased to the north of the storm along the Middle Atlantic coast.

Upper-level jet characteristics

- o Jet streak characteristics of the cyclone-associated trough and flanking ridges
 - A jet streak amplified from 50 to 70 m s⁻¹ in the downstream ridge over New England by 1200 GMT 19 January within a highly confluent region. Missing wind values are noted over New England and southeastern Canada in the following 24 h, indicating that winds may have continued to increase in magnitude during this period. The heaviest precipitation to the north and northeast of the storm center appeared to develop and expand in areal coverage in the entrance region of the jet as it propagated eastward between 1200 GMT 19 and 1200 GMT 20 January.
 - A 50 to 60 m s⁻¹ jet streak over the southwestern United States was located upwind of the digging trough on 19 January and appears to propagate toward the base of the trough along the Gulf Coast at 1200 GMT 19 and 0000 GMT 20 January.
 - It appears that the surface low is located to the anticyclonic side and in the entrance region of the jet streak centered across the northeastern United States between 1200 GMT 19 January to 0000 GMT 21 January, and may be located in the exit region of the jet propagating around the base of the trough during the same period.

500 MB HEIGHTS AND UPPER-LEVEL WINDS

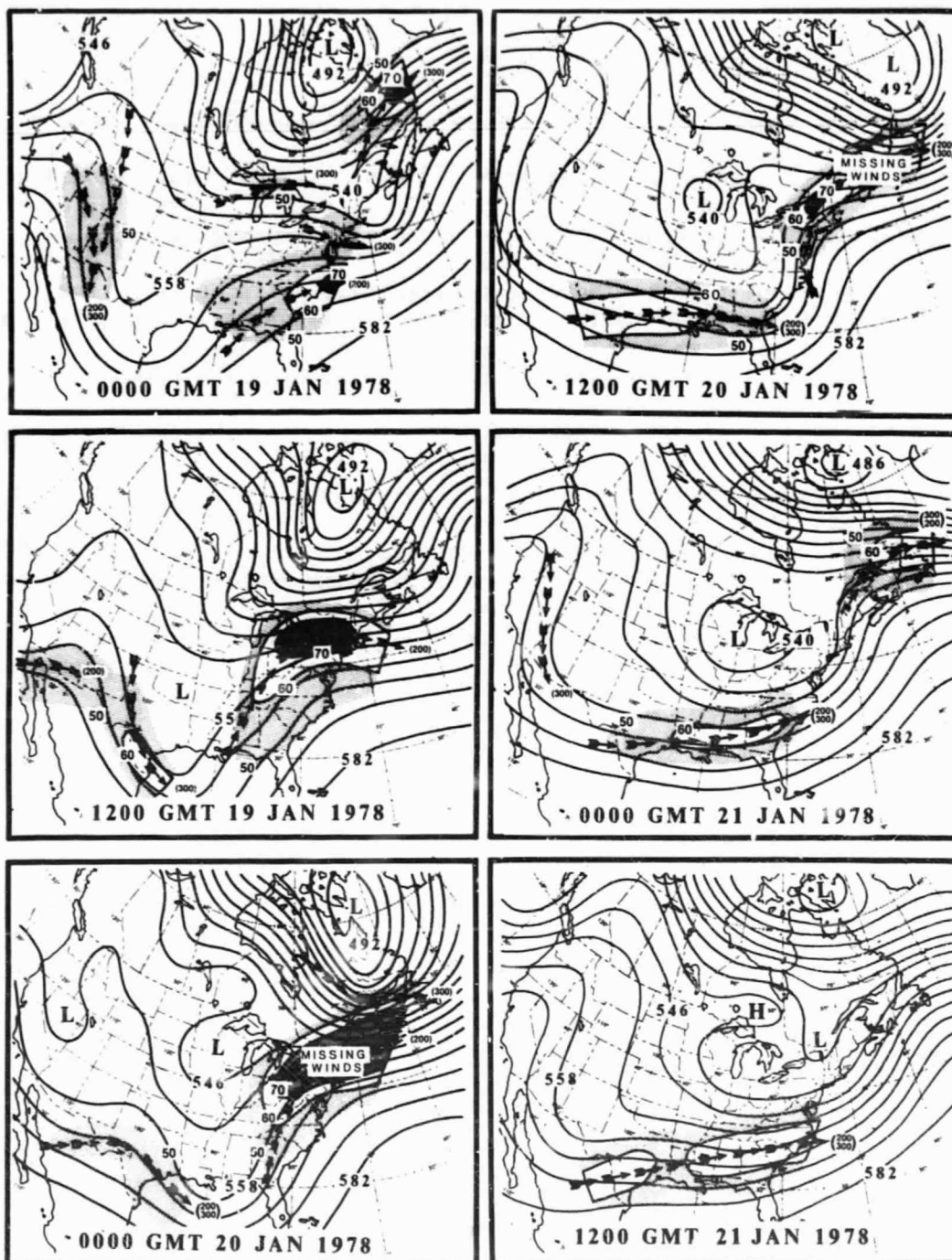
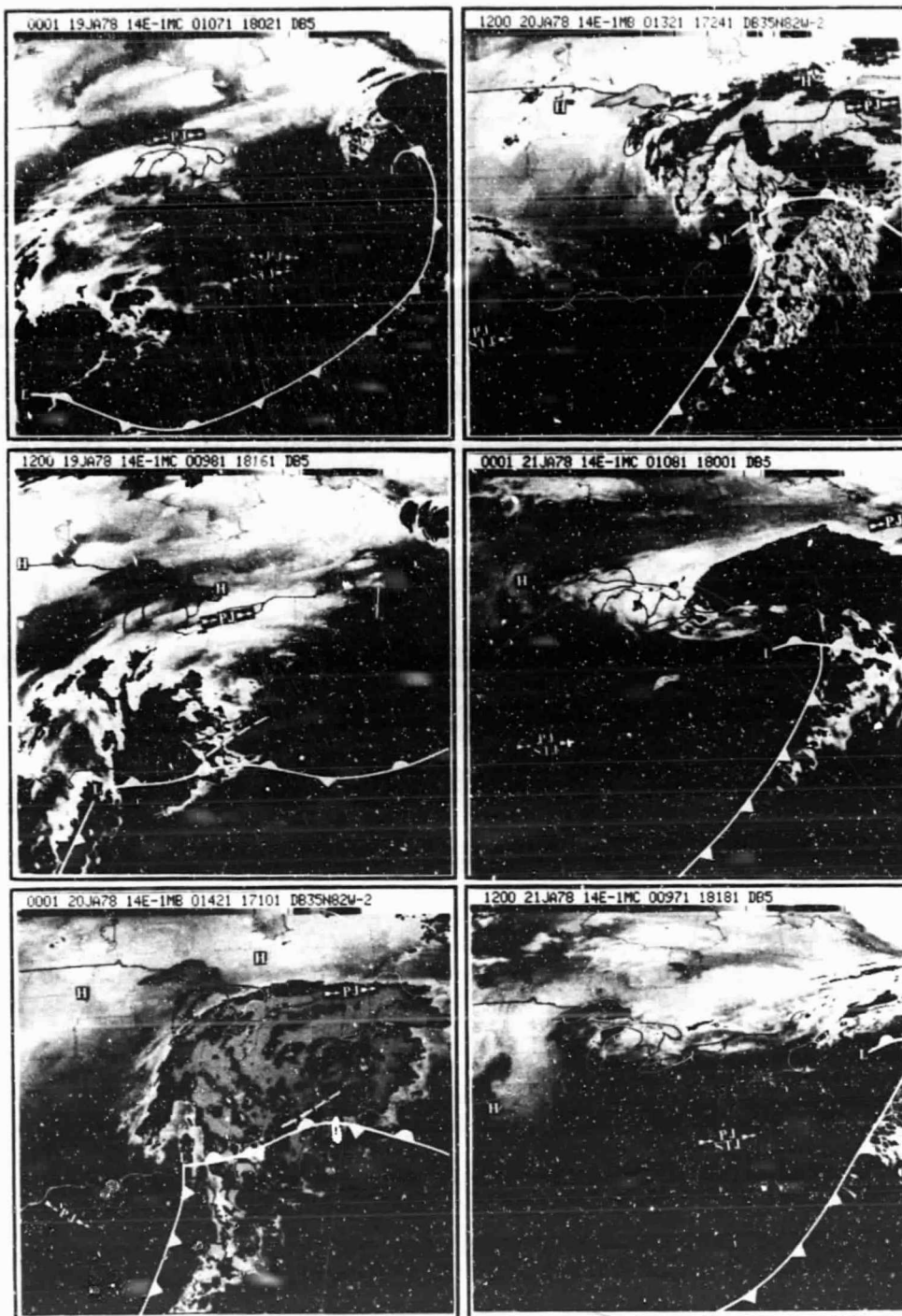


Fig. 56. The 500 mb geopotential height analyses and isotachs of maximum wind speeds for 0000 GMT 19 January, 1200 GMT 19 January, 0000 GMT 20 January, 1200 GMT 20 January, 0000 GMT 21 January, and 1200 GMT 21 January 1978. See Fig. 4 caption for details.

Infrared satellite imagery sequence

- o The initial development of the cyclone in the Gulf of Mexico was characterized by an intense cold cloud core south of Louisiana at 0000 GMT 19 January, that moved over Florida by 1200 GMT 19 January. This area may have contained intense convective elements.
- o The rapid northeastward expansion of the high cloud shield on 19 and 20 January extends over 1000 km north of the surface low pressure center. The expansion occurred in the entrance region of the amplifying polar jet over the northeastern United States. The sharp northern edge of the high cloud mass corresponds with the axis of the confluent upper-level flow just north of New England.
- o A clear tongue (no upper-level clouds) developed along the Gulf Coast at 0000 GMT 20 January and moved to the Middle Atlantic coast by 1200 GMT 20 January. The surface low appears to be located very close to the eastern edge of the clear tongue or along the western edge of the cloud region. The clear tongue lies along the axis of the upper-level jet located downwind of the trough axis (see 500 mb heights and upper-level winds chart).
- o A distinct comma shape to the upper cloud mass developed by 0000 GMT 21 January as the northern half of the cloud mass pivoted to the northeast while the comma "tail" drifted to the east. The comma shape evolved as the upper-level trough axis became more negatively tilted.
- o Heaviest precipitation was first located within the broad cloud expanse through 1200 GMT 20 January but then shifted toward the southern and western edge of the "comma head" as the low moved toward New England.

Note: Cloud top temperature scale "gray-scale" at 0000 GMT and 1200 GMT 20 January differs from the scale at other times.



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Fig. 57. GOES-East infrared satellite images for 0001 GMT 19 January, 1200 GMT 19 January, 0001 GMT 20 January, 1200 GMT 20 January, 0001 GMT 21 January, and 1200 GMT 21 January 1978.

6-7 February 1978

o General Remarks

- Hurricane-force winds and record-breaking snowfall made this storm one of the most intense this century for the northeastern United States. The cyclone was forecast remarkably well several days in advance by operational numerical forecast models (Brown and Olson, 1978). However, many were stranded on the roads in the New York City area because the onset of heavy snow occurred slightly later than predicted during the Monday morning rush hour. People were generally skeptical of the forecasts after a series of inaccurate forecasts of winter weather during the preceding month. The most severely affected regions were Long Island, Connecticut, Rhode Island, and Massachusetts. This storm is a remarkable example of sudden and rapid cyclonic development associated with a major trough amplification at 500 mb.

o Regions with snow accumulations exceeding 10 in (25 cm)

- eastern Maryland, Delaware, eastern Pennsylvania, New Jersey, southeastern, northeastern and portions of western New York, Connecticut, Rhode Island, Massachusetts, central and southern Vermont, New Hampshire, and Maine

o Regions with snow accumulations exceeding 20 in (51 cm)

- sections of northeastern Pennsylvania, northern New Jersey, western and southeastern New York, Connecticut, Rhode Island, Massachusetts, Vermont, New Hampshire, and Maine

o Urban center snowfall amounts:

Washington, D.C.-National Airport	2.2" (6 cm)
Baltimore, Md.	9.1" (23 cm)
Philadelphia, Pa.	14.1" (36 cm)
New York, N.Y.-Central Park	17.7" (45 cm)
Boston, Ma.	27.1" (69 cm)

o Other selected snowfall amounts:

Woonsocket, R.I.	38.0" (97 cm)
Rockport, Ma.	32.5" (83 cm)
Providence, R.I.	28.6" (73 cm)
Rochester, N.Y.	25.8" (66 cm)
Riverhead, N.Y.	25.0" (64 cm)
Worcester, Ma.	20.2" (51 cm)
Hartford, Ct.	16.9" (43 cm)
Trenton, N.J.	16.1" (41 cm)
Wilmington, De.	14.5" (37 cm)

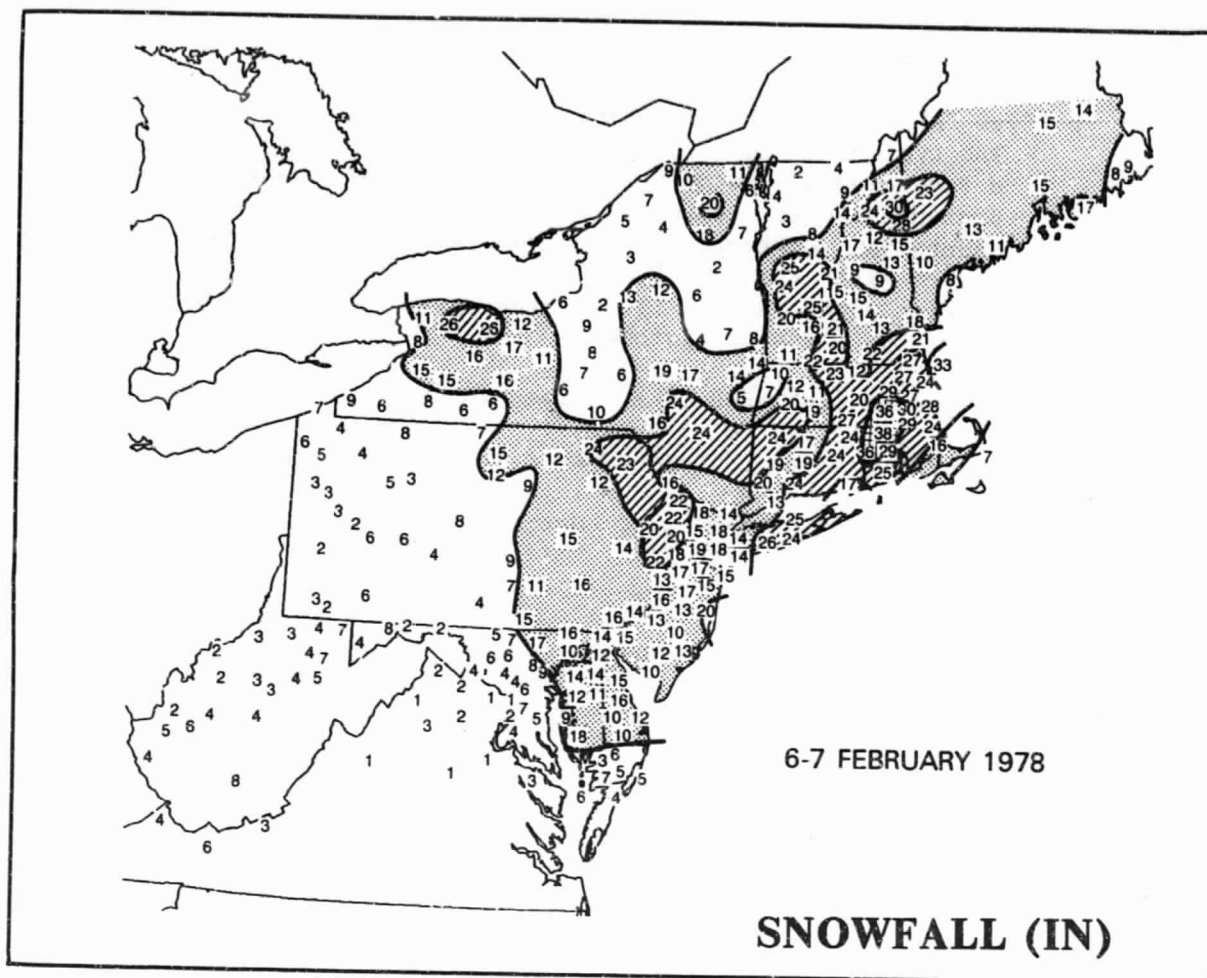


Fig. 58. Total snow accumulations for 6 to 7 February 1978 (in). See Fig. 1 caption for details.

Surface characteristics

- o Type "A" or "B" (Miller, 1946)
 - The cyclone is more reminiscent of type "B" since it involved a redeveloping low center over the ocean while an initial low pressure center stalled and filled over the Appalachian Mountains. However, the cyclone also resembled a type "A" system since the rapidly intensifying surface low did not develop along surface frontal features associated with the first low pressure system.
- o The cyclone developed in a regime dominated by unseasonable cold weather associated with unusually high pressure. A 1055 mb anticyclone north of North Dakota preceded the storm, with two axes of high pressure dominating the pre-cyclogenetic period before 0000 GMT 6 February. One axis extended down the center of the country and the other extended from New England southward to the southeastern United States.
- o There was no coastal frontogenesis observed for this case. However, there was weak cold air damming, as displayed by a ridge of high pressure along the East Coast on 5 February.
- o The initial primary low center remained weak as it drifted southeastward from Lake Superior to Pennsylvania on 5 February, and dissipated once the main storm developed east of the Carolinas coast. The central pressure remained above 1020 mb, and only light to moderate snows were associated with this system.
- o The rapid cyclone development occurred over the Atlantic Ocean between 0000 GMT and 1200 GMT 6 February. The low developed in a data void region, but appeared to deepen explosively (-3 mb (3 h)^{-1}) or greater) between 0600 GMT 6 February and 0000 GMT 7 February as the low moved to the north-northwest toward Long Island. Since the cyclone developed in a regime dominated by high pressure, it deepened only to 984 mb at its most intense stage, ranking only 13 of 18 in terms of lowest sea-level pressure.
- o The surface low initially propagated at approximately 10 to 12 m s^{-1} as it moved northward from well off the North Carolina coast to a position just south of Long Island on 6 February. It then drifted very slowly eastward just south of New England through 7 February, prolonging the heavy snowfall from Long Island to eastern New England. The surface low may have actually performed a small loop as it drifted south of Long Island late on 6 February.
- o The pressure gradient to the north and west of low center intensified on 6 February as gale-to-hurricane-force

northeasterly winds drifted the heavy snowfall, reducing ceiling and visibilities to near-zero over a large area.

- o The "backlash" of the storm was significant with heavy snow accumulations in excess of 25 cm southwest of the low center over Maryland and Delaware on the 6th and early on the 7th of February.

SURFACE

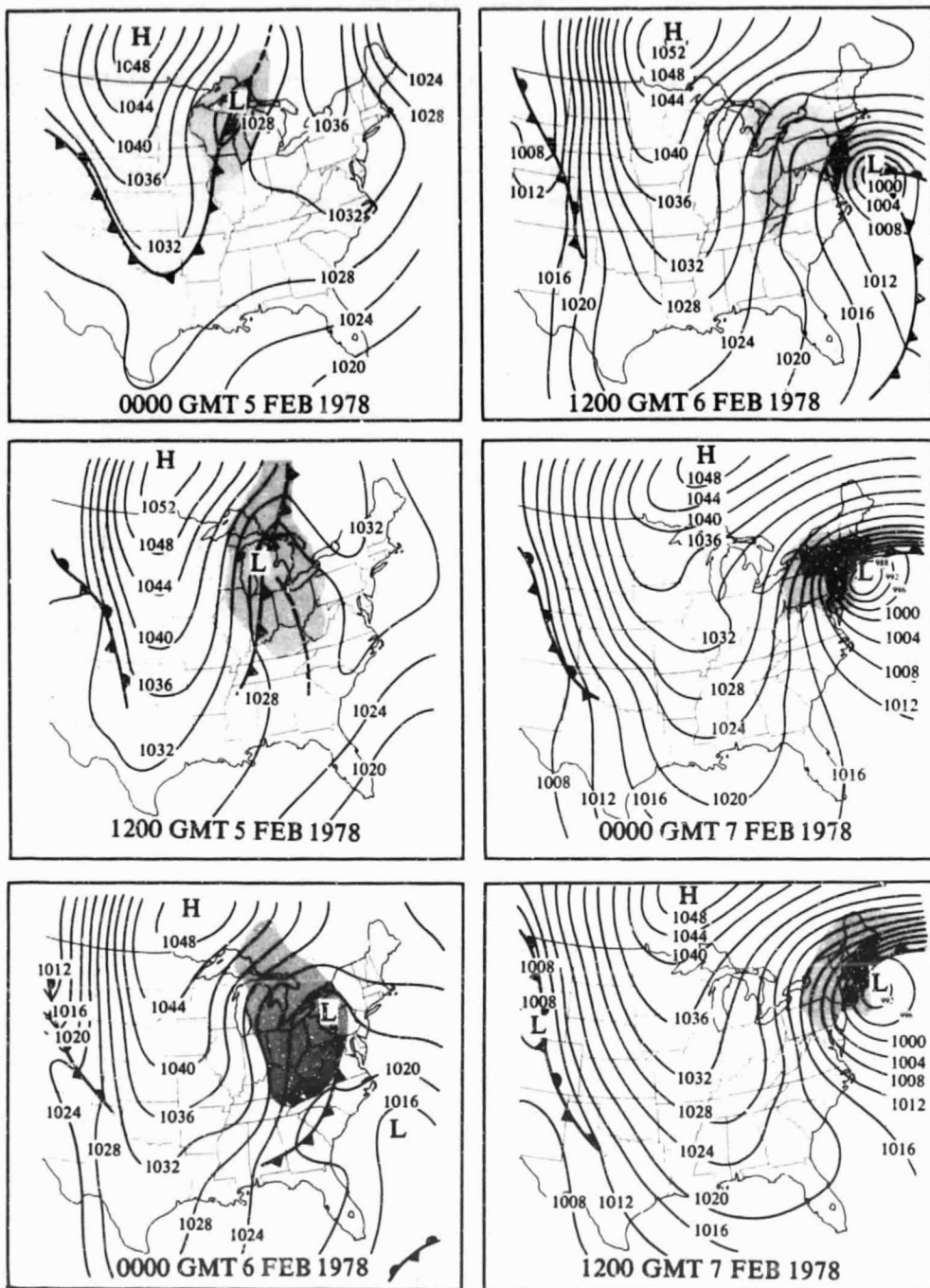


Fig. 59. Surface frontal and weather analyses for 0000 GMT 5 February, 1200 GMT 5 February, 0000 GMT 6 February, 1200 GMT 6 February, 0000 GMT 7 February, and 1200 GMT 7 February 1978. See Fig. 2 caption for details.

850 mb characteristics

- o 850 mb northwesterly flow and cold advection across the northeastern United States preceded the storm on 4 to 5 February.
- o A weak 850 mb low dropped southeastward across the Great Lakes between 0000 GMT 5 February and 0000 GMT 6 February and deepened very slowly. A new 850 mb low center formed off the Virginia coast by 1200 GMT 6 February, moved northward to off the New Jersey coast by 0000 GMT 7 February where it deepened explosively ($-150 \text{ m (12 h)}^{-1}$) and then drifted to the east without any further deepening by 1200 GMT 7 February. Much of the 850 mb deepening occurred over a 12 h period ending at 0000 GMT 7 February.
- o The re-formation of the 850 mb low center is first evident by 0000 GMT 6 February when largest height falls are located in the Carolinas, displaced a considerable distance from the primary 850 mb low center, located near Buffalo, N.Y.
- o The coastal low developed along an "S"-shaped isotherm pattern evident at 0000 GMT and 1200 GMT 6 February.
- o The second 850 mb low developed along a region of enhanced temperature gradients surrounding the 0°C isotherm after 0000 GMT 6 February with the first low imbedded deeply within the cold air. The thermal gradients intensified during the rapid development phase on 6 February.
- o A strong easterly jet with velocities exceeding 30 m s^{-1} developed rapidly to the north of the cyclone center in conjunction with explosive cyclogenesis between 1200 GMT 6 February and 0000 GMT 7 February. The development of this jet coincided with the rapid northward and westward expansion of snowfall along the Middle Atlantic and New England coasts, indicating that moisture transports and ascending motions associated with the jet were important elements in the development of heavy snowfall in the northeastern United States.

850 MB

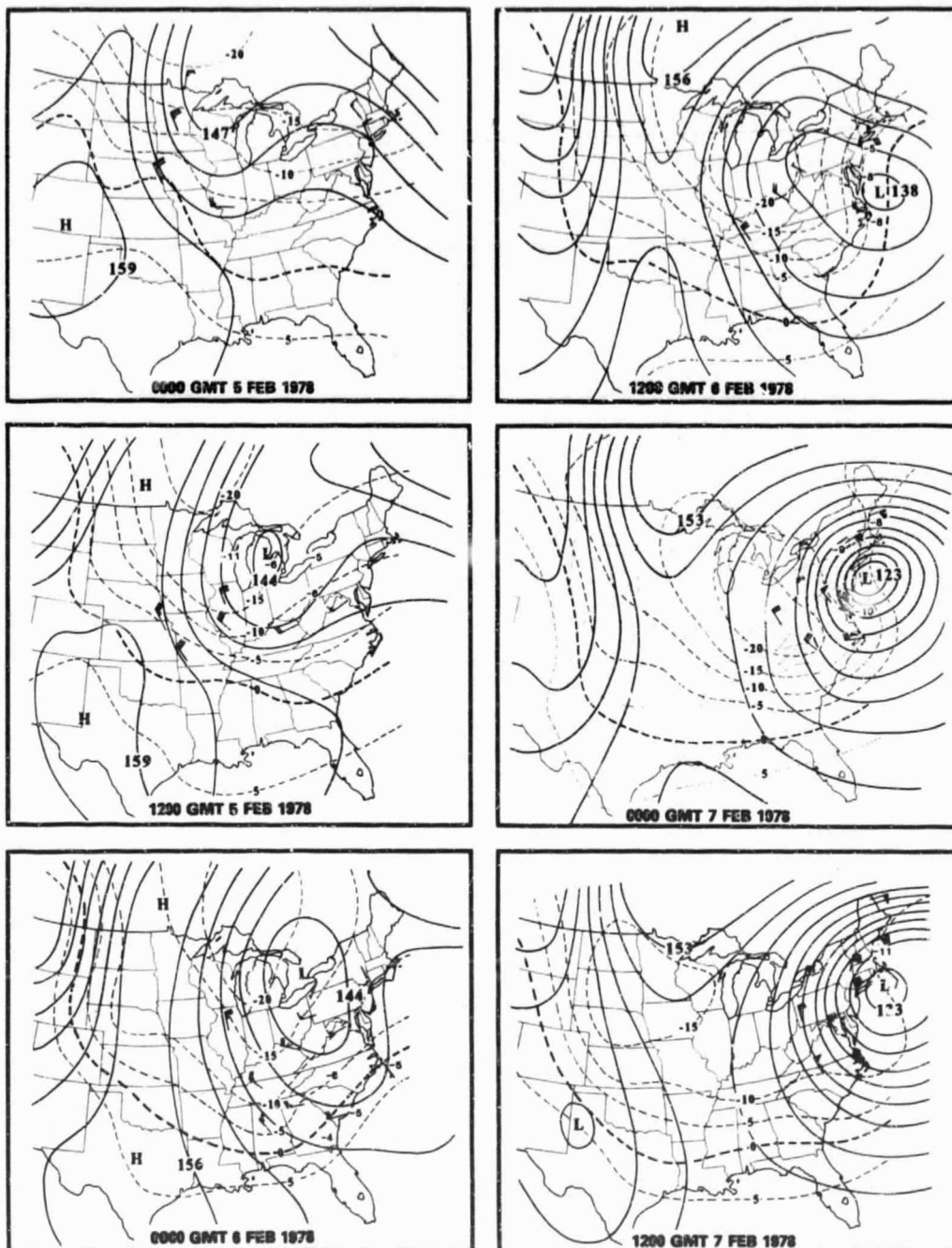


Fig. 60. The 850 mb analyses for 0000 GMT 5 February, 1200 GMT 5 February, 0000 GMT 6 February, 1200 GMT 6 February, 0000 GMT 7 February, and 1200 GMT 7 February 1978. See Fig. 3 caption for details.

500 mb geopotential height characteristics

- o General features prior to cyclogenesis along the East Coast
 - Four pronounced geopotential features are observed on 5 February prior to East Coast cyclogenesis, including a cut-off vortex over southeastern Canada, a cut-off ridge over Greenland, an open wave trough across south-central Canada and the Great Lakes, and a high amplitude ridge across the western United States and Canada. The southeastern Canadian vortex was associated with strong confluence over New England and was located over the surface pressure ridge across the northeastern United States. The ridge in the western United States amplified as an open wave trough in central Canada, that was later associated with the major storm, dropped southeastward toward the Ohio Valley.
 - The East Coast cyclone developed as the flow regime across North America was undergoing a remarkable transformation. The 500 mb flow regime changed from nearly zonal flow (prior to 5 February) to strongly meridional (by 5 or 6 February) to large, symmetrical vortices (7 February). The ridge along the West Coast developed a cut-off center in central Canada by 7 February. The south-central Canadian trough produced a cut-off vortex on the East Coast as the low exploded off the Middle Atlantic states, and a blocking pattern developed by 7 February. The rest of the month was characterized by persistent cold and dry weather in the Northeast that was related to the position of the upper-level vortex, which drifted from the northeastern United States into eastern Canada after 7 February.
- o Characteristics of trough associated with East Coast cyclogenesis
 - The 500 mb trough is an excellent example of a "digging" system which was centered over southern Hudson Bay at 1200 GMT 5 February and evolved into an intense vortex off the Virginia coast by 0000 GMT 7 February. An extremely diffluent region developed just downstream of the trough axis from 1200 GMT 5 February to 1200 GMT 6 February.
 - The trough attained an extremely negative tilt on 6 February. The explosive deepening of the surface low occurred as the negatively tilted diffluent portion of the trough moved off the East Coast on 6 February. Heavy precipitation and the surface low center were located within the diffluent portion of the trough at 0000 GMT 7 February as well.
 - Geopotential values at the vortex center did not drop appreciably between 0000 GMT 6 February and 0000 GMT 7 February, despite the dramatic changes in the trough structure during rapid cyclogenesis.
 - Amplitude changes are a dramatic aspect of the cyclogenetic period. The amplitude of the trough and upstream ridge increased greatly from 0000 GMT 5 February through 0000 GMT 7 February (the latitudinal separation of the 562 dam contour at ridge and trough axis increased from 14° to greater than 30°). The amplitude of the trough and downstream ridge increased most rapidly between 1200 GMT

5 February and 0000 GMT 7 February, but was not as pronounced as the upstream amplification.

- The half-wavelength between the trough and upstream ridge increased prior to East Coast cyclogenesis at 1200 GMT 6 February, while the half-wavelength between the trough and downstream ridge decreased between 0000 GMT 6 and 7 February as the explosive cyclogenesis was underway off the coast.

Upper-level jet characteristics

- o Jet streak characteristics of the cyclone-associated trough and flanking ridges
 - A subtropical jet (50 m s^{-1} at 200 mb) is observed off the Southeast coast prior to cyclogenesis at 1200 GMT 5 and 0000 GMT 6 February and appears to become incorporated within the cyclone-producing trough as the trough moved toward the southeastern United States by 0000 GMT 6 February (see the IR satellite sequence).
 - A polar jet streak (60 to 70 m s^{-1}) was located upwind of the trough axis prior to cyclogenesis and appeared to remain just to the west of the diffluent portion of the trough as the system propagated toward the East Coast on 5 and 6 February. It also appears that the development of the cyclone commenced as diffluence downwind of the trough axis and the exit region of the polar jet approached the coast (where vorticity advections and upper-level divergence would be expected to the large). At 1200 GMT 6 February, a separate jet maximum located east of the trough axis appeared along the coast as the height gradients amplified. The outbreak of heavy snowfall along the Northeast coast coincided with the formation of this feature.

500 MB HEIGHTS AND UPPER-LEVEL WINDS

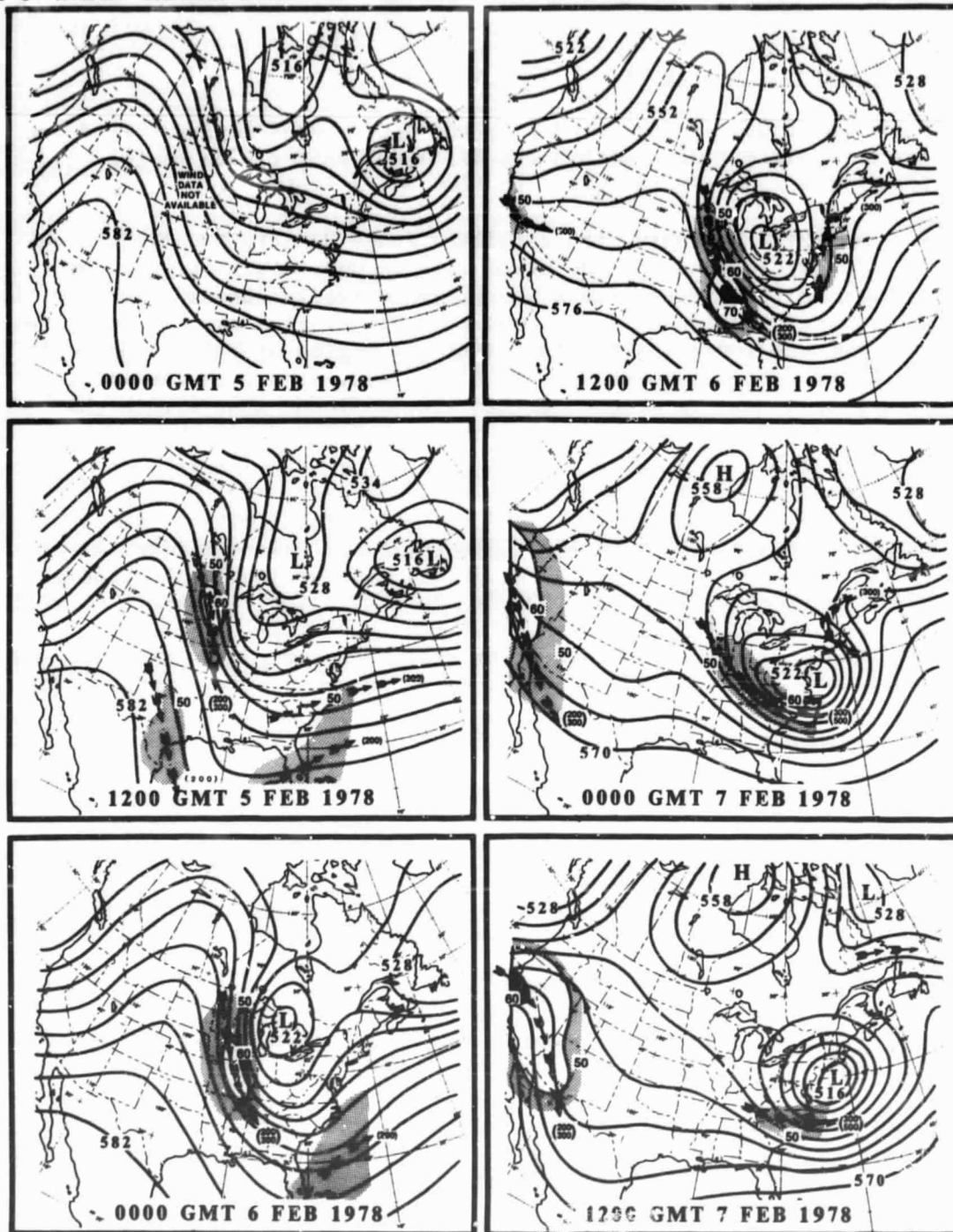
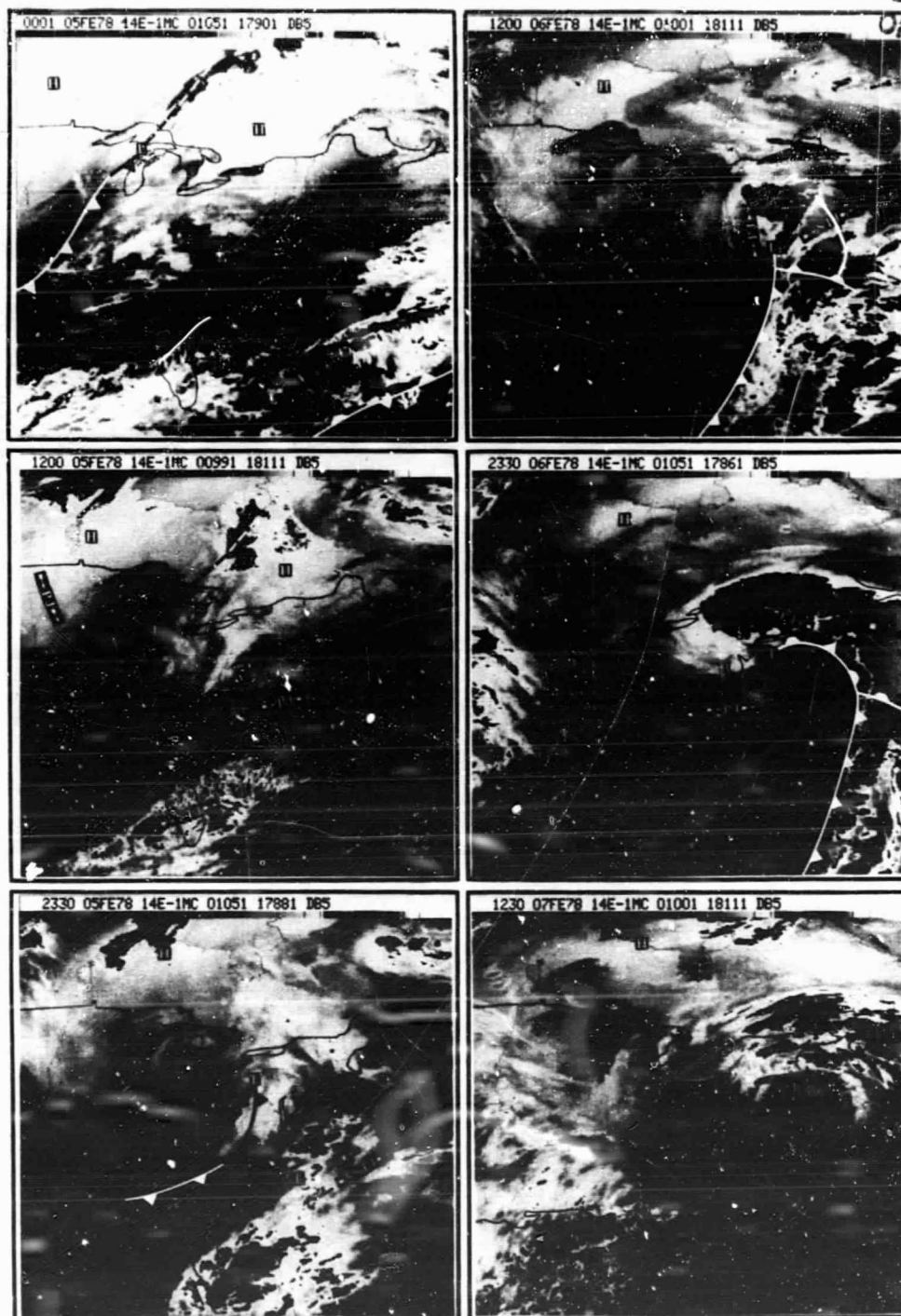


Fig. 61. The 500 mb geopotential height analyses and isotachs of maximum wind speeds for 0000 GMT 5 February, 1200 GMT 5 February, 0000 GMT 6 February, 1200 GMT 6 February, 0000 GMT 7 February, and 1200 GMT 7 February 1978. See Fig. 4 caption for details.

Infrared satellite imagery

- o A diffuse cloud system moved from the Great Lakes region toward the eastern United States within the diffluent exit region of the trough/polar jet system prior to 1200 GMT 5 February.
- o By 2330 GMT 5 February, the satellite image depicts the first stage of major cyclogenesis. The cloud mass is more distinct over the eastern United States with a sharp, cyclonically curved back edge. An expanding region of cold cloud tops off Florida may be associated with the subtropical jet. An additional region of colder tops off the North Carolina coast appears to be associated with the initial cyclogenesis and is located within the diffluent zone within the eastern portion of the trough as the trough started to become negatively tilted.
- o By 1200 GMT 6 February, the cloud feature earlier off Florida moved northeastward, resembling the "warm conveyor belt" described by Carlson (1980). In addition, the cloud mass originally located off North Carolina expanded northward. This cold top cloud mass moved westward across the northeastern states by 0000 GMT 7 February, coinciding with the development of strong easterly flow at lower and upper levels as the 500 mb vortex moved to the Virginia coast. The cloud mass associated with the subtropical jet continued moving to the northeast out over the Atlantic Ocean.
- o The configuration of 1) the northeastward-moving, anticyclonically-curved cloud mass, associated with the subtropical jet that propagated over the Atlantic Ocean and 2) the westward-propagating and rapidly expanding cloud mass over the northeastern United States, presents some of the general features of the comma-shape cloud pattern associated with mid-latitude cyclones as discussed by Carlson (1980).
- o During cyclogenesis (especially on 6 February), the surface low center was located immediately to the south of the region of highest (coldest) cloud tops.
- o Heaviest snowfall appeared to occur along the southern edge of the coldest tops of the cloud mass wrapping back toward the west over the Middle Atlantic states and southern New England around the storm center on 6 and 7 February.
- o As the low center occluded off the New England coast by 1230 GMT 7 February, the cloud mass spiraled around the low center with coldest cloud tops, now disorganized, located to the north of the low center.
- o A pronounced "eye"-like center was observed in visible images (see Fig. 11 in Part 1) on the morning of 7 February as the system occluded.



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Fig. 62. GOES-East infrared satellite images for 0001 GMT 5 February, 1200 GMT 5 February, 2330 GMT 5 February, 1200 GMT 6 February, 2330 GMT 6 February, and 1230 GMT 7 February 1978.

18-19 February 1979

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o General Remarks

- This heavy snowstorm hit the Middle Atlantic states with record snow amounts on the "Presidents' Day" holiday. The cyclone has been the subject of numerous studies (Bosart, 1981; Newell, 1981; Uccellini et al., 1983, 1984a, b; Atlas, 1984) since the rapidly developing storm on 19 February was poorly forecast by operational models. Accumulations in excess of 24 in (51 cm) occurred in areas just south and east of Washington, D.C., as well as scattered locations between Washington, D.C. and Baltimore, Md., where snowfall rates approached 5 in (12 cm) per hour on the morning of 19 February (Foster and Leffler, 1979). The snowstorm occurred at the end of a massive cold outbreak with snow cover as far south as southern Georgia (see Fig. 10 in Part 1). The storm marked the end of a two-week period of extreme cold across the northeastern United States.

o Regions with snow accumulations exceeding 10 in (25 cm)

- portions of West Virginia and Virginia (especially northern Virginia), Maryland, Delaware, southern Pennsylvania, most of New Jersey, and New York City

o Regions with snow accumulations exceeding 20 in (51 cm)

- parts of Maryland, Delaware, and New Jersey

o Urban center snowfall amounts:

Washington, D.C.-National Airport	18.7" (47 cm)
Baltimore, Md.	20.0" (51 cm)
Philadelphia, Pa.	14.3" (36 cm)
New York, N.Y.-Central Park	12.7" (32 cm)

o Other selected snowfall amounts:

Dover, De.	25.0" (64 cm)
Atlantic City, N.J.	17.1" (43 cm)
Newark, N.J.	16.6" (42 cm)
Wilmington, De.	16.5" (42 cm)
Harrisburg, Pa.	14.2" (36 cm)
Richmond, Va.	10.9" (28 cm)

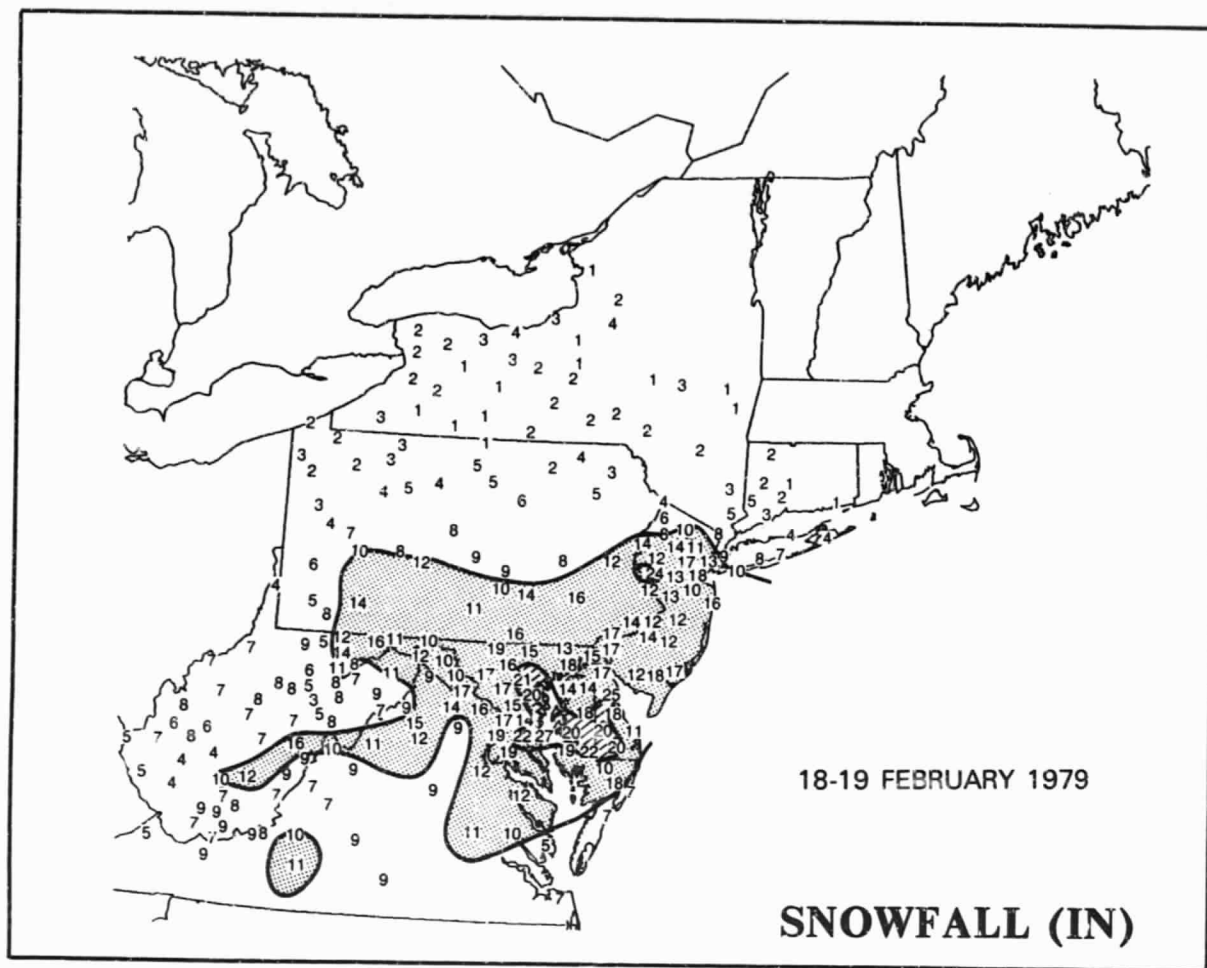


Fig. 63. Total snow accumulations for 18 to 19 February 1979 (in). See Fig. 1 caption for details.

TOTAL SNOWFALL (INCHES)
18-19 FEBRUARY 1979
METROPOLITAN WASHINGTON, D.C.

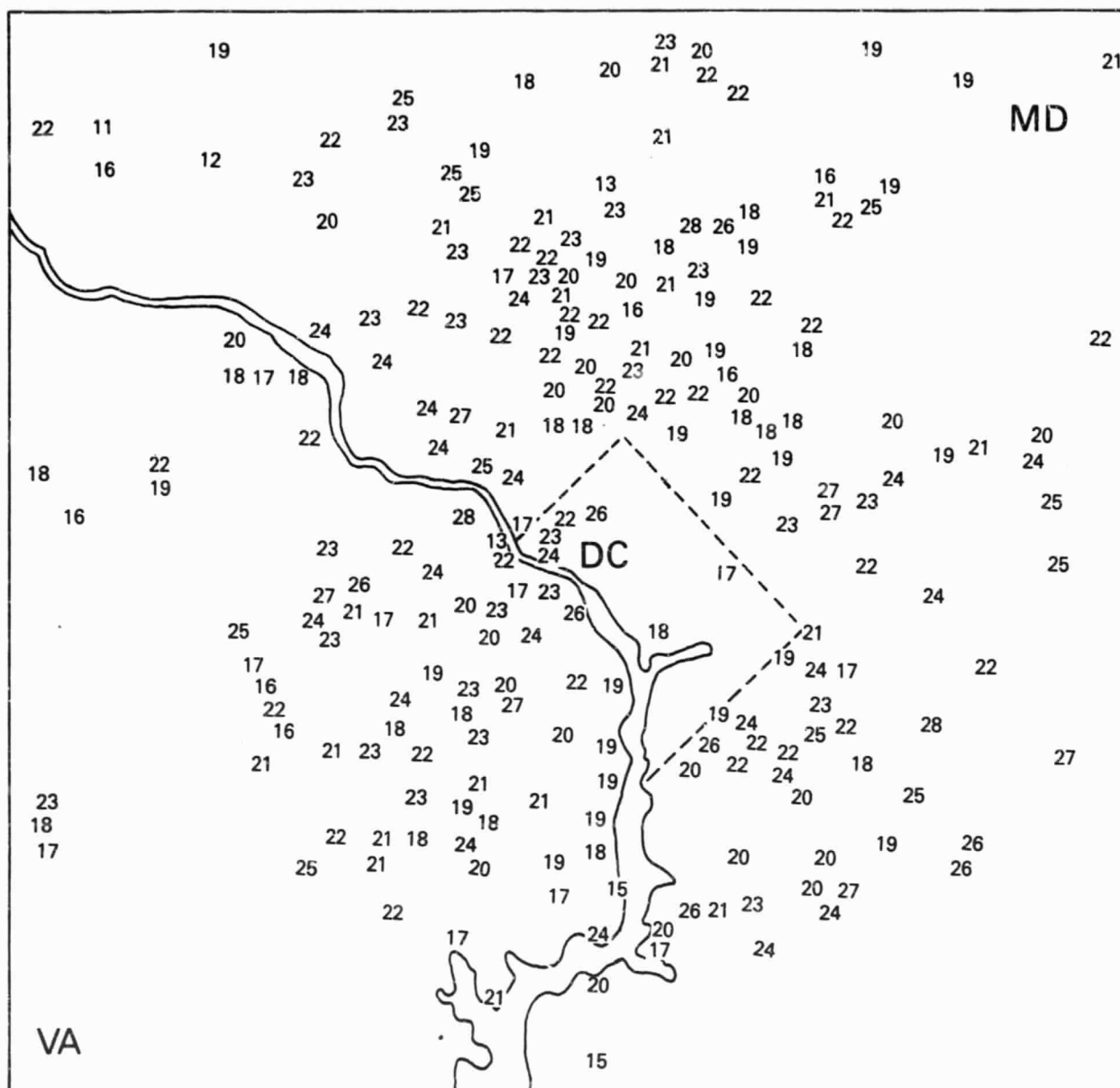


Fig. 64. Total snow accumulations for 18 to 19 February 1979 (in) for the Washington, D.C. metropolitan area. Snowfall measurements were taken from the Metropolitan Washington Climate Review for February 1979.

Surface characteristics

- o The cyclone was preceded by a large anticyclone (1050 mb) that was accompanied by record cold temperatures in the eastern half of the United States.
- o Pronounced damming of cold air occurred to the lee of the Appalachian Mountains on 18 February.
- o Type "A" or "B" (Miller, 1946).
 - An inverted trough formed across Tennessee and the Ohio Valley on 18 February. A surface low pressure center formed over Kentucky within the trough late on 18 February, but the low had no frontal characteristics. This initial low deepened to only 1024 mb over the Ohio Valley and produced light to moderate snows just south of the Great Lakes on 18 February. Heavier snows developed across portions of Ohio, West Virginia, and Pennsylvania late on 18 February and early on 19 February. The low dissipated during secondary East Coast cyclogenesis.
 - The secondary low developed off the East Coast late on 18 February and intensified rapidly off the Virginia and Maryland coasts on 19 February.
- o The secondary cyclone developed along an intense coastal front off the Georgia-Carolina coasts on 18 February. Heavy snow and frozen precipitation across the southeastern United States preceded the formation of the cyclone early on 18 February.
- o The storm deepened rapidly after 0000 GMT 19 February, with deepening rates approaching -2 to -3 mb h^{-1} after 1200 GMT 19 February.
- o This cyclone also developed in a regime of very high sea-level pressure and deepened only to 995 mb (based on NMC analyses) east of the Maryland coast.
- o Heavy snowfall occurred as the central pressure of low center remained above 1000 mb. Heaviest snow fell on the morning of 19 February across the Middle Atlantic states during the rapid development phase of the storm.
- o The initial movement of the low was northeastward along the coastal front through the morning of 19 February to a position just east of the Maryland coast. The subsequent movement was to the east out over the Atlantic Ocean.
- o Surface maps and satellite photos indicate that the cyclonic circulation covered a relatively small area.

SURFACE

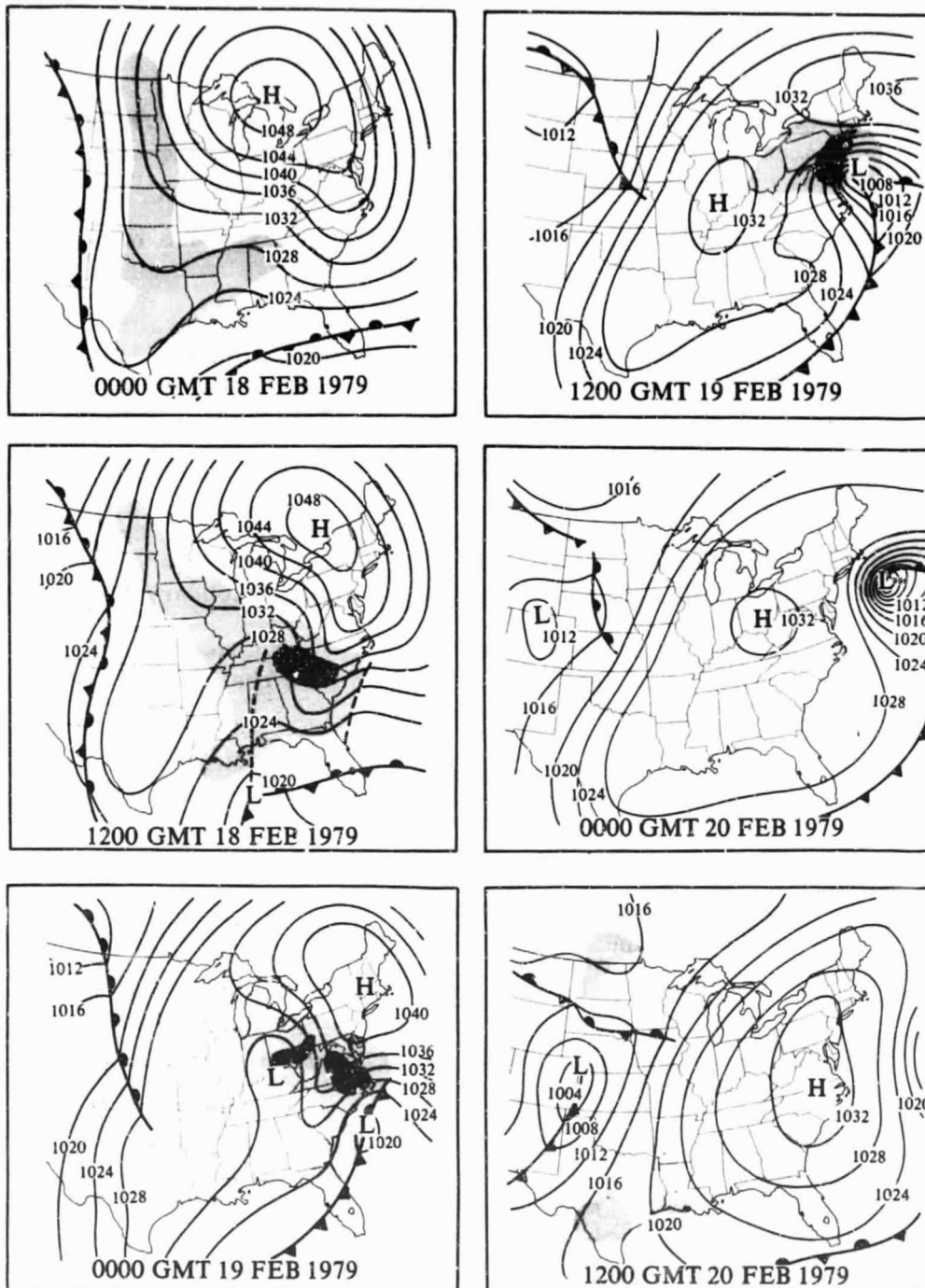
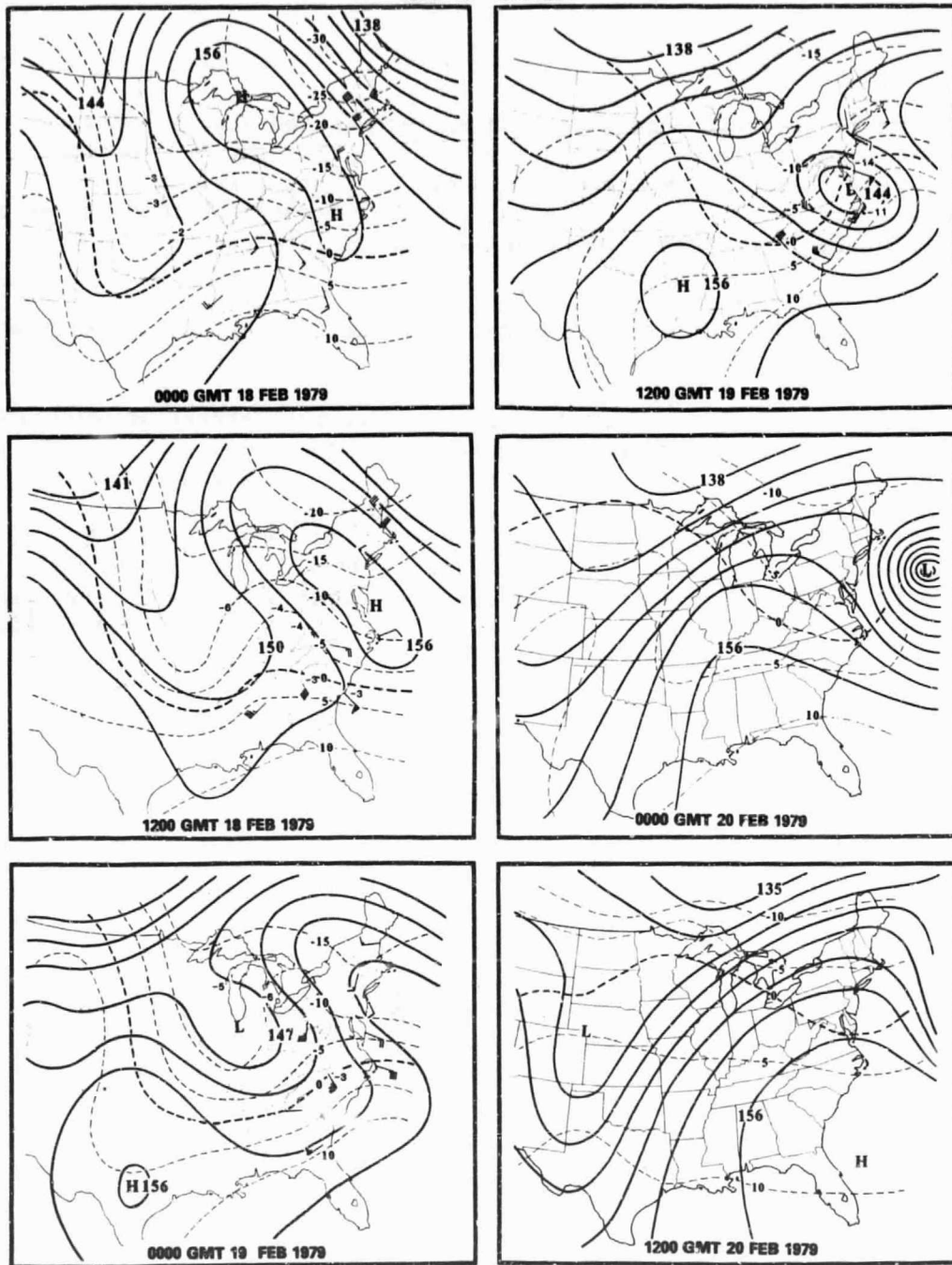


Fig. 65. Surface frontal and weather analyses for 0000 GMT 18 February, 1200 GMT 18 February, 0000 GMT 19 February, 1200 GMT 19 February, 0000 GMT 20 February, and 1200 GMT 20 February 1979. See Fig. 2 caption for details.

850 mb characteristics

- o A large 850 mb ridge dominated the eastern United States prior to East Coast cyclogenesis. Cold advection to the east of the ridge axis left the 0°C isotherm as far south as South Carolina with temperatures well below -20° across the northeastern United States on 17 February in northwesterly flow associated with upper-level confluence.
- o 850 mb temperatures were much lower over the New England and Middle Atlantic states preceding the storm than following it.
- o A low center at 850 mb formed over the midwestern states at 0000 GMT 19 February well to the north of the 0°C isotherm and the largest 850 mb temperature gradient. This low center and a separate height fall center across the southeastern United States merged into a deepening low center along the Middle Atlantic coast by 1200 GMT 19 February. The magnitude of the deepening rates after 1200 GMT 19 February are uncertain as the surface low deepened in a data void region off the East Coast. The 850 mb low center along the Atlantic Coast at 1200 GMT 19 February was colocated with the 0°C isotherm.
- o An "S"-shaped isotherm pattern accompanied cyclogenesis on 19 February.
- o A southeasterly, ageostrophic low-level jet with winds up to 25 m s^{-1} formed across Georgia and South Carolina by 1200 GMT 18 February during a period in which the subtropical jet amplified (see Uccellini et al., 1984) and as the wavelength between the upper-level trough and downstream ridge shortened.
- o The low-level jet formed simultaneously with the development of a coastal front and precipitation across the southeastern United States, and occurred in conjunction with a height fall center across the southeastern United States in a region of large 850 mb temperature gradients, sensible and latent heating, and cold air damming near the earth's surface (see Uccellini et al., 1983).
- o The low-level jet was observed further north along the East Coast during the following 24 h ending at 1200 GMT 19 February and was a significant factor in doubling the moisture transports into the region of heavy snowfall on 18 and 19 February (Uccellini et al., 1984).

850 MB



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Fig. 66. The 850 mb analyses for 0000 GMT 18 February, 1200 GMT 18 February, 0000 GMT 19 February, 1200 GMT 19 February, 0000 GMT 20 February, and 1200 GMT 20 February 1979. See Fig. 3 caption for details.

500 mb geopotential height characteristics

- o Details on the evolution of upper-level features can be found in Uccellini et al. (1984, 1985). See Bosart (1981) for surface and quasi-geostrophic analyses.
- o General features prior to cyclogenesis along the East Coast
 - Strongly confluent flow across the northeastern United States on 16 and 17 February was associated with the movement of a very cold anticyclone from the Great Lakes to New England. The cyclone developed after a weak trough crossed the country and amplified into a pronounced short wave trough with rather small areal coverage.
- o Characteristics of trough associated with East Coast cyclogenesis
 - Cyclogenesis occurred in association with an open wave trough that did not develop a closed center at 500 mb. The height minimum at the trough axis did not deepen after 1200 GMT 18 February.
 - Two short wave features, one over Montana and the other over New Mexico at 1200 GMT 17 February (not shown), appear to merge into one trough over the Ohio Valley prior to cyclogenesis. The northern short wave feature "digs" southeastward between 1200 GMT 17 February and 0000 GMT 19 February as the geopotential gradients at the base of the trough intensified over the Ohio Valley by 0000 GMT 19 February. Uccellini et al. (1984, 1985) show that a tropopause fold associated with this trough extruded stratospheric air with high potential vorticity down to the 700 mb level at this time.
 - Diffluence downwind of the trough axis became more noticeable between 1200 GMT 18 February and 0000 GMT 19 February and coincided with the formation of the inverted trough and low pressure center over the Ohio Valley. The trough appeared to have a slight negative tilt by 1200 GMT 19 February as the surface low was deepening rapidly off the East Coast.
 - The amplitude of the trough appears to actually decrease in the 12 h period between 0000 GMT and 1200 GMT 19 February during rapid cyclogenesis.
 - The expansion of the precipitation shield on 18 February and rapid cyclogenesis on 19 February occurred as the half-wavelength between trough and downstream ridge decreased.

Upper-level wind analyses

- o See Uccellini et al. (1984, 1985) for a general description of the jet streaks influencing the development of the "Presidents' Day" storm.
- o Jet streak characteristics of the cyclone-associated trough and flanking ridges

- The amplification of a subtropical jet streak near 200 mb occurred at the crest of the downwind ridge prior to East Coast cyclogenesis as heavy snow developed across the southeastern United States by 1200 GMT 18 February. The wind speeds increased from 60 to 80 m s⁻¹ between 1200 GMT 17 February and 1200 GMT 18 February with a noticeable cross-contour component of the flow developing near the ridge crest. The increasing divergence associated with the subtropical jet contributed to the initial area of frozen precipitation in the southeastern United States.
- A weaker polar jet streak (50 m s⁻¹), associated with the amplifying trough, propagated from the Northern Plains to the East Coast between 0000 GMT 18 February and 1200 GMT 19 February. The tropopause fold occurred along the axis of this jet. Strongest winds near the base of the trough occurred as rapid cyclogenesis commenced along the East Coast at 1200 GMT 19 February. The explosive development of the secondary area of precipitation across the Middle Atlantic states occurred within the diffluent exit region of this jet between 0000 GMT and 1200 GMT 19 February as the polar jet propagated toward the East Coast.

500 MB HEIGHTS AND UPPER-LEVEL WINDS

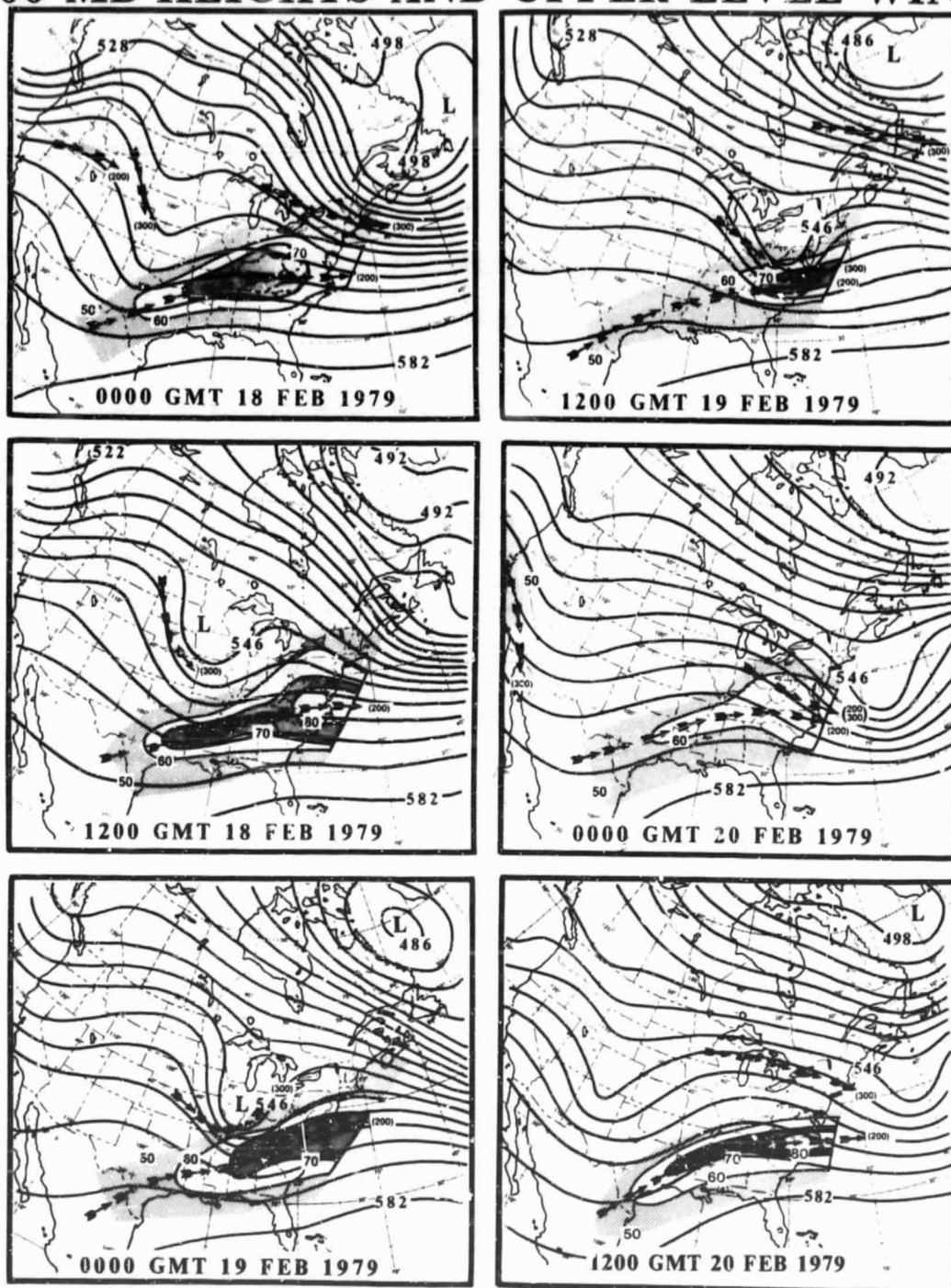
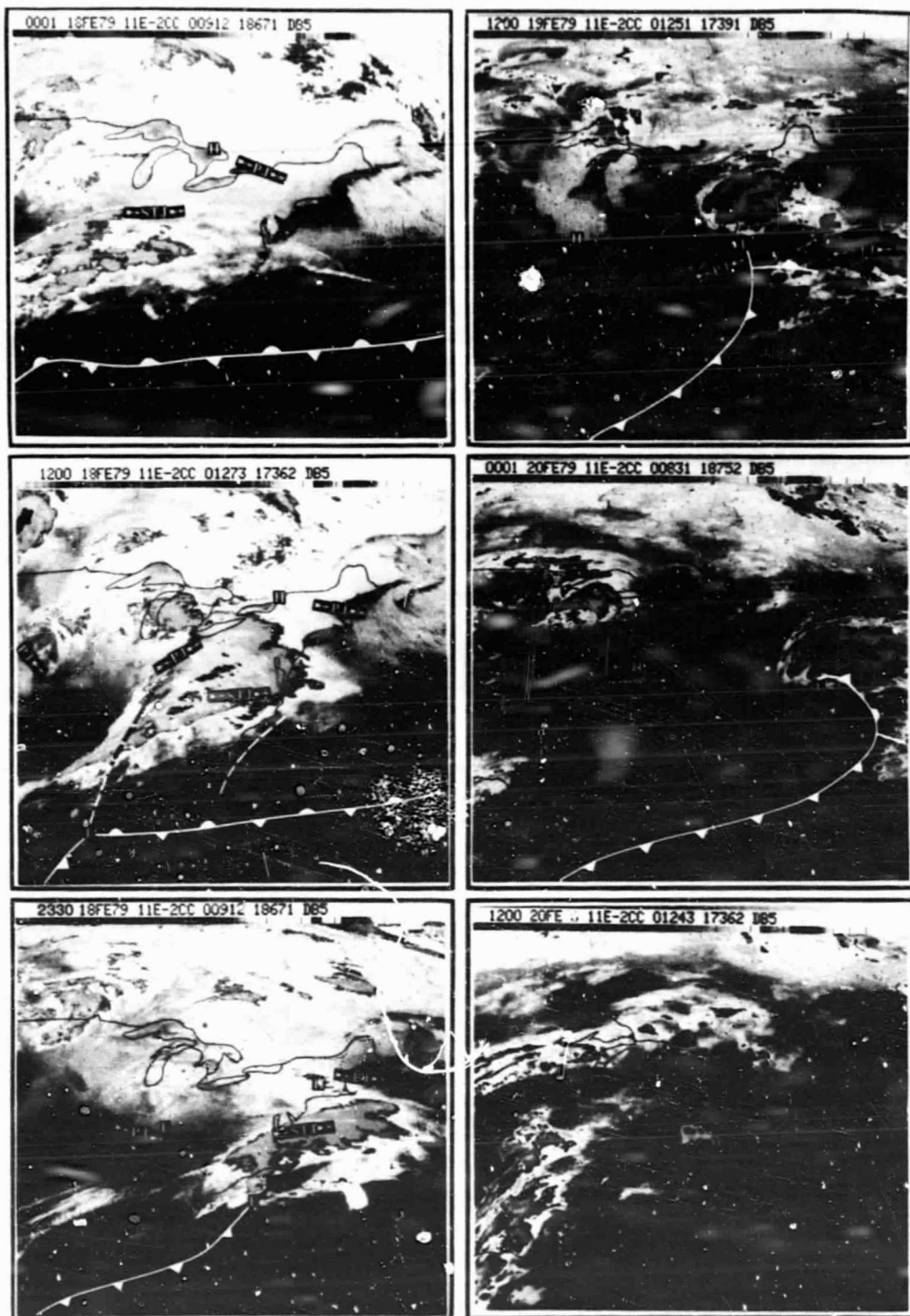


Fig. 67. The 500 mb geopotential height analyses and isotachs of maximum wind speeds for 0000 GMT 18 February, 1200 GMT 18 February, 0000 GMT 19 February, 1200 GMT 19 February, 0000 GMT 20 February, and 1200 GMT 20 February 1979. See Fig. 4 caption for details.

Infrared satellite imagery

- o The cyclone and heavy snowfall were associated with two separate cloud mass systems.
- o The first cloud system can be seen as a mass of cold cloud tops between 0000 GMT 18 February and 2330 GMT 18 February, streaming eastward along the axis of the subtropical jet. The heaviest precipitation fell along the southern edge of this cloud system on 18 February, producing heavy snow and frozen precipitation across Kentucky, Tennessee, Georgia, and the Carolinas. These clouds were moving off the East Coast as cyclogenesis commenced along the Carolina coast late on 18 February.
- o A second area of clouds appears as a small comma-shaped cloud area located over Nebraska and Iowa at 1200 GMT 18 February that traversed the eastern half of the country in 24 h. This cloud mass was located consistently in the exit region of the polar jet during this period. This system expanded rapidly in a 3 to 6 h period between 0900 GMT and 1500 GMT (see Uccellini et al., 1985) and exhibited much colder cloud top temperatures at 1200 GMT 19 February as the surface cyclone deepened rapidly off the Virginia-Maryland coast with very heavy snows in the Middle Atlantic states. Coldest cloud top temperatures are found to the north of the surface low with heaviest snows located from the coldest cloud top area near New York City at 1200 GMT 19 February southward to the edge of colder cloud tops over northern Virginia.
- o The cyclone attained a classic "comma" shape over the Atlantic Ocean between 1200 GMT 19 February and 0000 GMT 20 February.
- o The development of an "eye" over the Atlantic by 1800 GMT 19 February (see Fig. 11 in Part 1) occurred as the storm went through an explosive development phase.



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Fig. 68. GOES-East infrared satellite images for 0001 GMT 18 February, 1200 GMT 18 February, 2330 GMT 18 February, 1200 GMT 19 February, 0001 GMT 20 February, and 1200 GMT 20 February 1979.

5-7 April 1982

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o General Remarks

- This unusual late-season storm produced near-blizzard conditions in New York City, Boston, and much of Pennsylvania, New York, and New England. The rapidly intensifying cyclone spread heavy snow amounts across the Midwest and Ohio Valley before affecting the northern half of the Middle Atlantic states and New England. The snow and cold temperatures associated with the storm were responsible for postponing opening day of the Major League baseball season in many cities. Thunderstorms with frequent lightning were reported in New York City during the heaviest snowfall. The storm was followed by one of coldest April air masses on record (Boston, Ma. remained near -10°C during the afternoon of 7 April). Numerical simulations were successful in forecasting the storm. (See Kaplan et al., 1982 for a mesoscale simulation of secondary surface redevelopment associated with this case.)

o Regions with snow accumulations exceeding 10 in (25 cm)

- portions of northern and eastern Pennsylvania, northern New Jersey, southeastern New York, and sections of southwestern New York, central and northern Connecticut and Rhode Island, Massachusetts (except the extreme southeast), southern Vermont and New Hampshire, and Maine

o Regions with snow accumulations exceeding 20 in (51 cm)

- scattered portions of eastern New York, southern Vermont, northeastern Massachusetts, and southeastern New Hampshire

o Urban center snowfall amounts:

Philadelphia, Pa.	3.5" (9 cm)
New York, N.Y.-Central Park	9.6" (24 cm)
Boston, Ma.	13.3" (34 cm)

o Other selected snowfall amounts:

Grafton, N.Y.	22.8" (58 cm)
Albany, N.Y.	17.7" (45 cm)
Portland, Me.	15.9" (40 cm)
Worcester, Ma.	15.0" (38 cm)
Hartford, Ct.	14.1" (36 cm)
Concord, N.H.	13.9" (35 cm)
Newark, N.J.	12.8" (33 cm)
Allentown, Pa.	11.4" (29 cm)

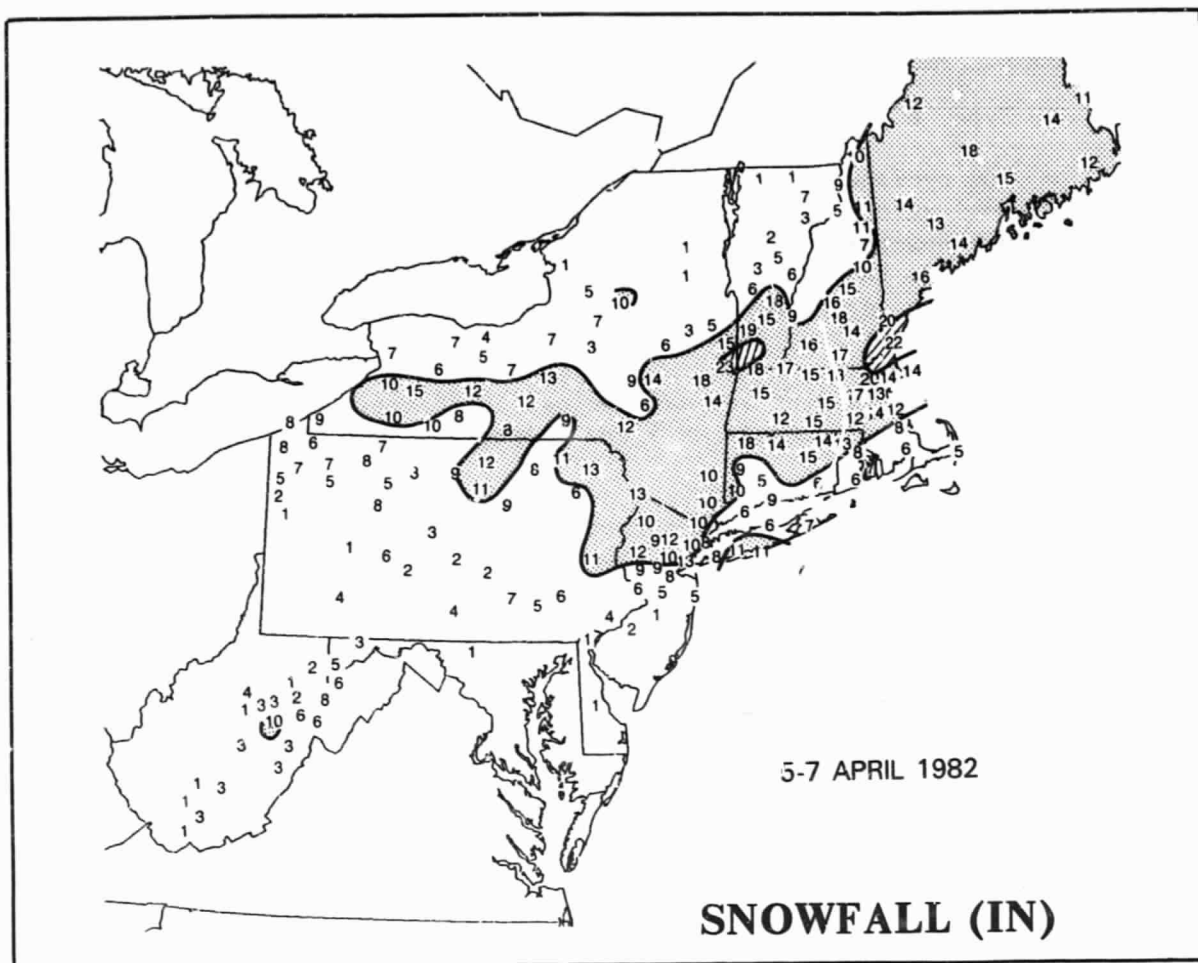


Fig. 69. Total snow accumulations for 5 to 7 April 1982 (in). See Fig. 1 caption for details.

Surface characteristics

- o Type "B" (Miller, 1946)
- o The cyclone developed south of a very cold (for April) anticyclone (1033 mb) over central Canada that extended into the northeastern United States. The anticyclone moved southward towards the Midwest following the storm where snow cover helped produce record cold temperatures from the Plains states to the East Coast on 6 through 8 April.
- o Cold air damming was weak across the Eastern States prior to and during cyclogenesis on 5 and 6 April.
- o Coastal frontogenesis was evident late on 5 April and early on 6 April, but was not characterized by the large temperature contrasts seen in other cases.
- o The primary low pressure system moved from the Southern Plains to the Ohio Valley to Pennsylvania by 1200 GMT 6 April, deepening 10 mb in 12 h ending at 0000 GMT 6 April as the low moved into western Pennsylvania. The primary low produced moderate to heavy snows and strong winds that spread eastward from Chicago to Detroit and Cleveland as the low moved through the Ohio Valley on 5 April. The primary low was absorbed very rapidly into the circulation of the secondary coastal storm by 1200 GMT 6 April.
- o The secondary low pressure system developed over North Carolina and Virginia between 0000 GMT and 1200 GMT 6 April and deepened explosively over an 18 h period at a rate of -1 to -3 mb h⁻¹ from 994 mb at 0900 GMT 6 April to 968 mb by 0000 GMT 7 April. Very heavy snow developed across the coastal regions of the Northeast and spread to the north and east during this stage of development. The low center passed east-northeastward off the Virginia-Maryland coast, south of Long Island and southern New England, and then northeastward toward Nova Scotia.
 - The secondary low pressure center propagated at a rate of 10 to 13 m s⁻¹ as it moved off the East Coast. The forward motion of the storm did not appear to decelerate near New England.
 - Snow generally fell within 24 h, and in many instances for a much briefer period with 1 to 2 in (2.5 to 5 cm) per h snowfall rates at the height of the storm.

SURFACE

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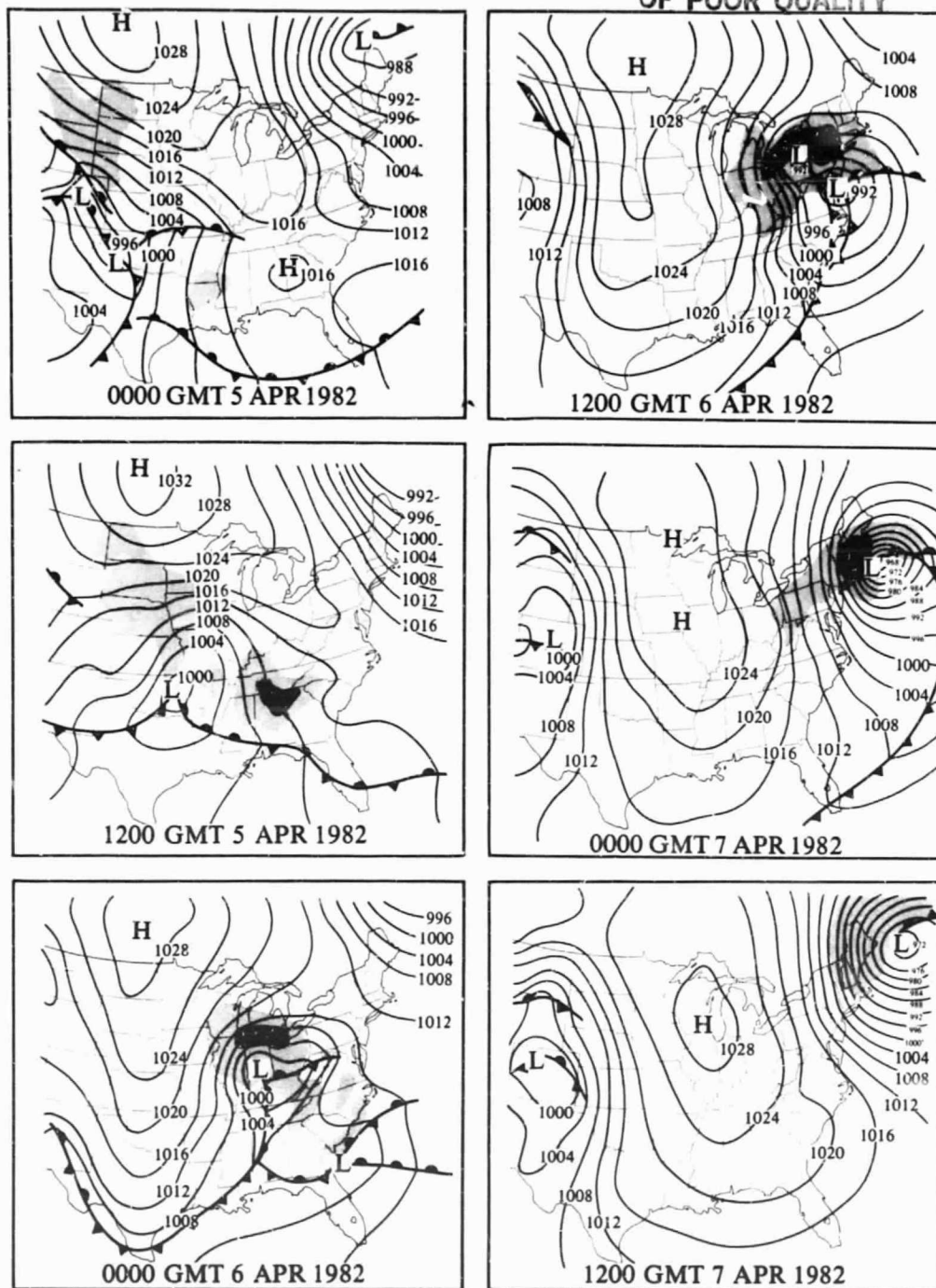


Fig. 70. Surface frontal and weather analyses for 0000 GMT 5 April, 1200 GMT 5 April, 0000 GMT 6 April, 1200 GMT 6 April, 0000 GMT 7 April, and 1200 GMT 7 April 1982. See Fig. 2 caption for details.

850 mb characteristics

- o Prior to East Coast cyclogenesis, cyclonic northwesterly flow across the northeastern United States to the rear of an intense cyclone in eastern Canada yielded strong cold advection on 4 and 5 April. The northwesterly flow and cold advection was imbedded beneath a region of upper-level confluence. The strong cold advection helped create a narrow, intense thermal gradient across the Middle Atlantic states on 5 April.
- o The 850 mb low deepened at an accelerating rate as it neared the East Coast. The 850 mb deepening occurred between 1200 GMT 5 April and 0000 GMT 7 April as the low moved from the central Plains to off southern New England. It deepened by 60 m (12 h)⁻¹ as it crossed the upper Mississippi Valley by 0000 GMT 6 April, by 90 m (12 h)⁻¹ as it approached the East Coast by 1200 GMT 6 April, and by 150 m (12 h)⁻¹ as it moved off the coast by 0000 GMT 7 April.
- o There is evidence of a secondary 850 mb geopotential height fall center across the southeastern United States at 0000 GMT 6 April, which may be a reflection of secondary surface low formation. This feature is difficult to follow at 1200 GMT 6 April as the entire 850 mb circulation has intensified over the eastern third of the country.
- o This case is marked by very strong temperature gradients during cyclogenesis with pronounced cold advection to the rear of the low and warm advection ahead of it. The advection patterns increased as the 850 mb low moved toward the East Coast at 0000 GMT and 1200 GMT 6 April.
- o An "S"-shaped isotherm pattern took shape at 0000 GMT and 1200 GMT 6 April as the 850 mb low was deepening and the surface low was intensifying near the Atlantic coast.
- o The 0°C isotherm was generally located near the center of the 850 mb low except by 1200 GMT 7 April, when the 850 mb low was centered in colder air during the occlusion stage.
- o No clearly defined jet formation is observed as high winds are associated with the 850 mb low throughout the study period. However, stronger southerly flow developed to the southeast and stronger easterly flow developed to the north of the rapidly intensifying 850 mb low by 0000 GMT 6 April and 0000 GMT 7 April, respectively.

850 MB

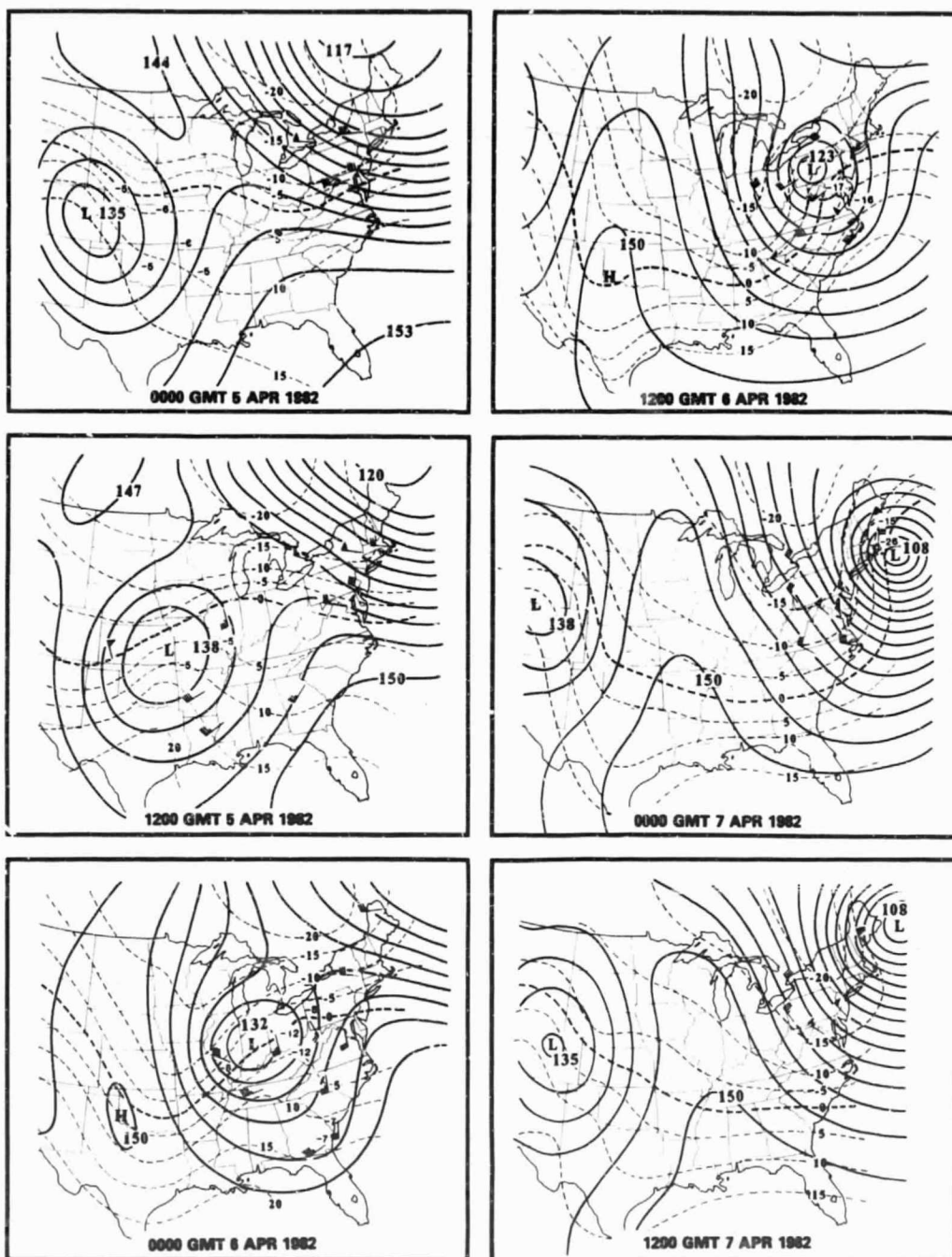


Fig. 71. The 850 mb analyses for 0000 GMT 5 April, 1200 GMT 5 April, 0000 GMT 6 April, 1200 GMT 6 April, 0000 GMT 7 April, and 1200 GMT 7 April 1982. See Fig. 3 caption for details.

500 mb geopotential height characteristics

- o General features prior to cyclogenesis along the East Coast
 - As a blocking cut-off ridge developed near Greenland on 5 April, an intense trough over southeastern Canada moved slowly eastward. This configuration produced significant confluent flow across the Great Lakes into the northeastern United States as the cold surface anticyclone became entrenched over the Great Lakes region on 5 and 6 April.
 - The cyclone developed as a short wave trough amplified within the strong westerly flow across the United States.
- o Characteristics of trough associated with East Coast cyclogenesis
 - The trough propagated from west to east across the United States from 4 to 7 April. The trough system was not a large amplitude system, but it amplified and formed a deepening closed center at 500 mb by 0000 GMT 7 April.
 - Geopotential gradients at the base of the trough increased between 0000 GMT and 1200 GMT 6 April as both primary and secondary surface low pressure centers intensified. Diffluence also became more apparent at these two time periods, with the trough becoming negatively tilted by 1200 GMT 6 April.
 - The explosive deepening phase of the surface cyclone and rapid development of heavy precipitation along the coast between 1200 GMT 6 April and 0000 GMT 7 April commenced as the diffluent region of the negatively tilted trough moved over the coast.
 - Although this case of intense cyclogenesis was associated with an amplifying trough, the amplification was manifested by only a small increase of amplitude between the trough and downstream ridge during cyclogenesis on 6 April. However, the half-wavelength between the trough and downstream ridge may have decreased during this period.

Upper-level jet characteristics

- o Jet streak characteristics of the cyclone-associated trough and flanking ridges
 - An intense polar jet ($>70 \text{ m s}^{-1}$) extended from the West Coast toward the base of the trough as the trough amplified in the middle of the United States between 0000 GMT 5 and 0000 GMT 6 April.
 - Missing wind reports over the Carolinas at 1200 GMT 6 April and an 80 m s^{-1} report at 0000 GMT 7 April indicate that the jet streak amplified near and upwind of the base of the trough immediately before the explosive development of the cyclone commenced around 1200 GMT 6 April. There is evidence (not shown) that tropopause folding occurred along the axes of this jet by 0000 GMT 6 April prior to secondary surface cyclogenesis.
 - As modeled by Kaplan et al. (1982), the storm system rapidly developed within the diffluent exit region of the polar jet streak/

trough system as it approached the East Coast between 0600 and 1200 GMT 6 April.

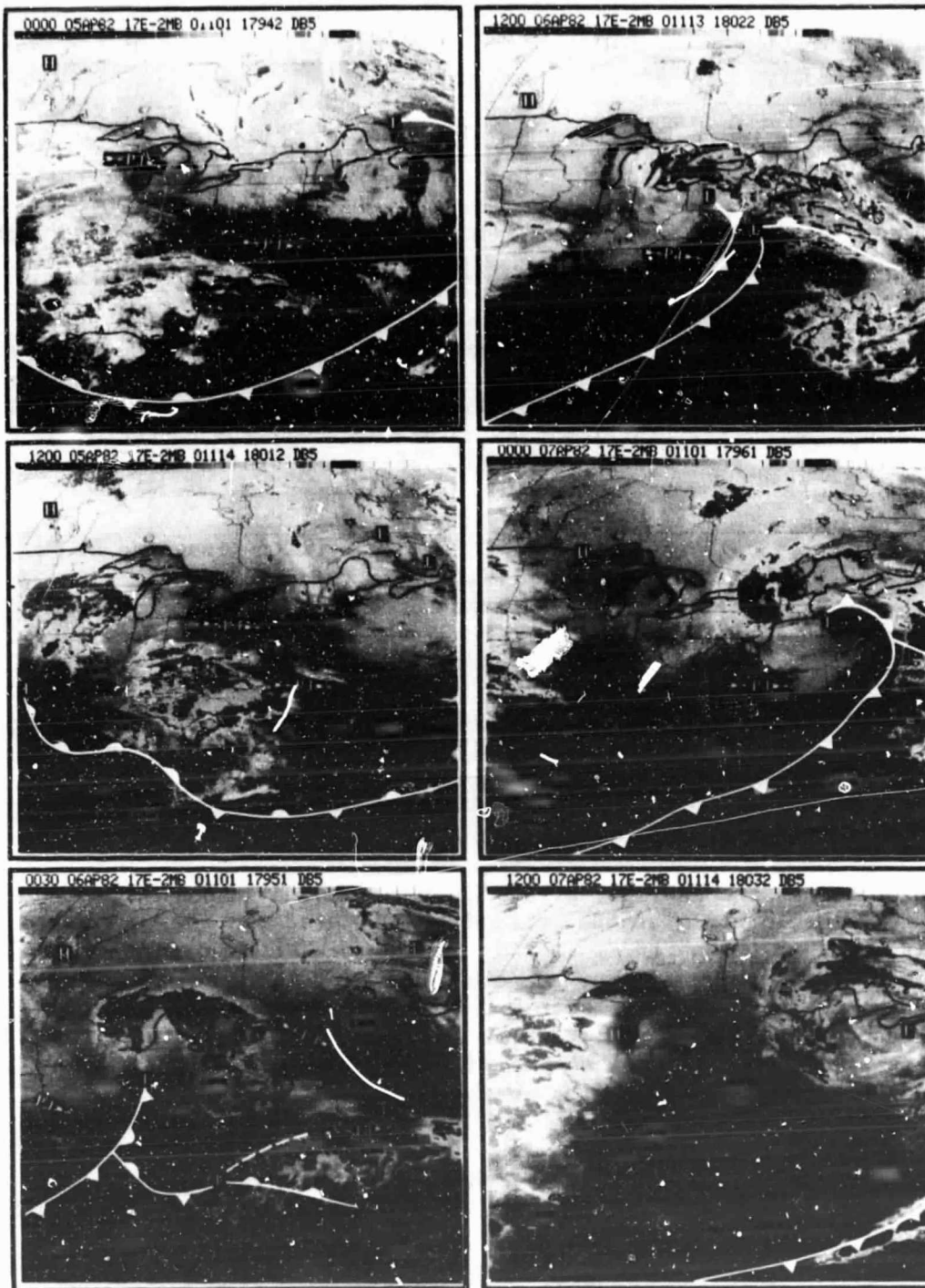
o Other jet characteristics

- An intense polar jet stretched across the eastern United States on 5 April within the confluent region upwind of the southeastern Canadian trough system. There is also evidence of a subtropical jet across the southeastern United States on 5 April.

Fig. 72. The 500 mb geopotential height analyses and isotachs of maximum wind speeds for 0000 GMT 5 April, 1200 GMT 5 April, 0000 GMT 6 April, 1200 GMT 6 April, 0000 GMT 7 April, and 1200 GMT 7 April 1982. See Fig. 4 caption for details.

Infrared satellite imagery

- o A distinct cloud mass with cold cloud tops was observed over the southeastern United States between 0000 GMT 5 April and 0000 GMT 6 April. These upper-level clouds were not directly associated with the amplifying upper-level trough but may be related to the subtropical jet off the southeastern United States coast between 0000 GMT 5 and 0000 GMT 6 April. The cold cloud top region was associated with a region of moderate rainfall across the southeastern United States at 1200 GMT 5 April. The cold cloud top temperatures off the Southeast Coast at 0000 GMT 6 April are located near a weak surface low. This center may be a reflection of the commencement of the secondary low, which developed over North Carolina and Virginia in the following 6 h.
- o The enhanced cold top cloud mass from Missouri to Minnesota at 1200 GMT 5 April is associated with the upper-level trough which spawned the cyclone and was located north of the surface low center over Oklahoma. This cloud mass remained in the diffluent exit region of the polar jet as it propagated toward the east.
- o A distinct, sharp back edge to the cloud mass is noted from Indiana to Alabama at 0030 GMT 6 April. It is later located immediately east of the coast at 1200 GMT 6 April and lies well out into the Atlantic by 0000 GMT 7 April. This edge appears to be colocated with the position of the surface cold front.
- o The cloud mass consolidated into a uniform comma-shaped cloud feature by 0000 GMT 7 April as the surface low deepened rapidly, but was displaced to the north of the surface low center with heaviest snows along the southern edge of the cloud feature. While the highest cloud top features were located to the east of the trough axis through 1200 GMT 6 April, they extended to the west of the trough axis by 0000 GMT 7 April as the 500 mb trough developed a closed center and snows fell to the north and west of the intense surface low.
- o This cloud feature evolved into the spiraling, cloud mass that characterized the occlusion stage of the cyclone by 1200 GMT 7 April.
- o An "eye" was briefly visible late on the afternoon of 6 April as the cyclone was deepening rapidly south of New England (see Fig. 11 in Part 1).



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Fig. 73. GOES-East infrared satellite images for 0000 GMT 5 April, 1200 GMT 5 April, 0030 GMT 6 April, 1200 GMT 6 April, 0000 GMT 7 April, and 1200 GMT 7 April 1982.

10-12 February 1983

2r. 10-12 FEBRUARY 1983

o General Remarks

- The axis of heaviest snows from this storm was aligned from Washington to Baltimore to Philadelphia to New York and to Boston.
- 24 h snowfalls were the greatest on record at Philadelphia, Pa., Harrisburg, Pa., Allentown, Pa., and Hartford, Ct. For many other cities, this was one of the heaviest snowstorms on record with 30 in (76 cm) accumulations in northern Virginia, western Maryland, and the panhandle of West Virginia. Thunderstorms were observed at numerous locations with frequent lightning and heavy snows from Washington, D.C. to New York City. The area of thunderstorms appeared to move northeastward from northern Virginia to southern New England from the afternoon to the late evening of 11 February. Winds were not as crippling as in other storms, but were still strong enough from New Jersey to Massachusetts to cause near-blizzard conditions. This was a remarkably heavy snowstorm which occurred in the midst of a very warm, stormy, but snowless winter for much of the northeastern sector of the nation.

o Regions with snow accumulations exceeding 10 in (25 cm)

- West Virginia (except near the Ohio and Kentucky borders), Virginia (except the extreme southwest and Tidewater), Maryland (except the extreme southeast), Delaware, the southeastern half of Pennsylvania, New Jersey, southeastern New York, Connecticut, Rhode Island, Massachusetts, and extreme southern New Hampshire

o Regions with snow accumulations exceeding 20 in (51 cm)

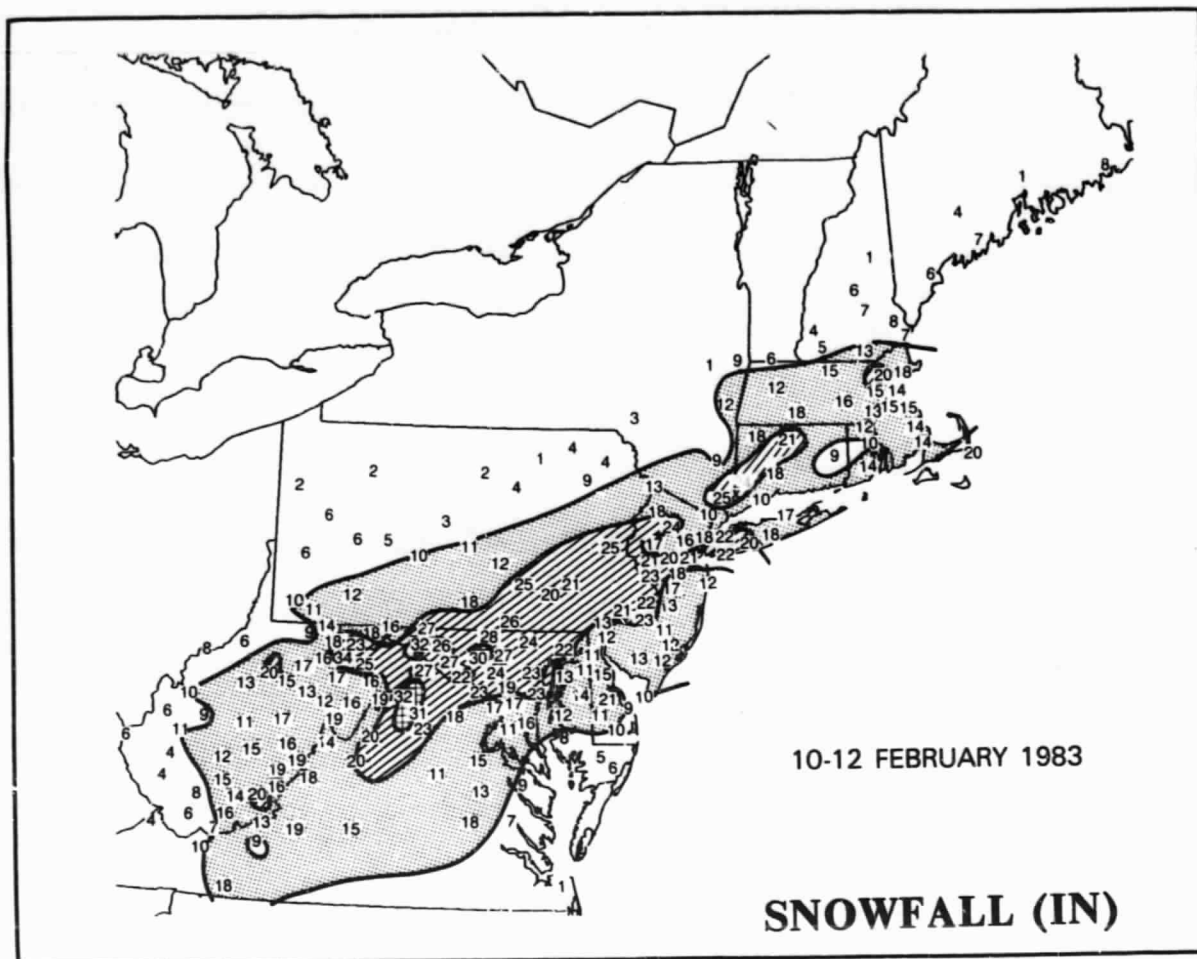
- northern Virginia, northeastern West Virginia, central and northern Maryland, southeastern Pennsylvania, central and northern New Jersey, southeastern New York, central Connecticut, and parts of Massachusetts

o Urban center snowfall amounts:

Washington, D.C.-Dulles Airport	22.8" (58 cm)
Baltimore, Md.	22.8" (58 cm)
Philadelphia, Pa.	21.3" (54 cm)
New York, N.Y.-La Guardia	22.0" (56 cm)
Boston, Ma.	13.5" (34 cm)

o Other selected snowfall amounts:

Woodstock, Va.	32.0" (81 cm)
Allentown, Pa.	25.2" (64 cm)
Harrisburg, Pa.	25.0" (64 cm)
Hartford, Ct.	21.0" (53 cm)
Roanoke, Va.	18.6" (47 cm)
Richmond, Va.	17.7" (45 cm)



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Fig. 74. Total snow accumulations for 10 to 12 February 1983 (in). See Fig. 1 caption for details.

TOTAL SNOWFALL (INCHES)
10-11 FEBRUARY 1983
METROPOLITAN WASHINGTON, D.C.

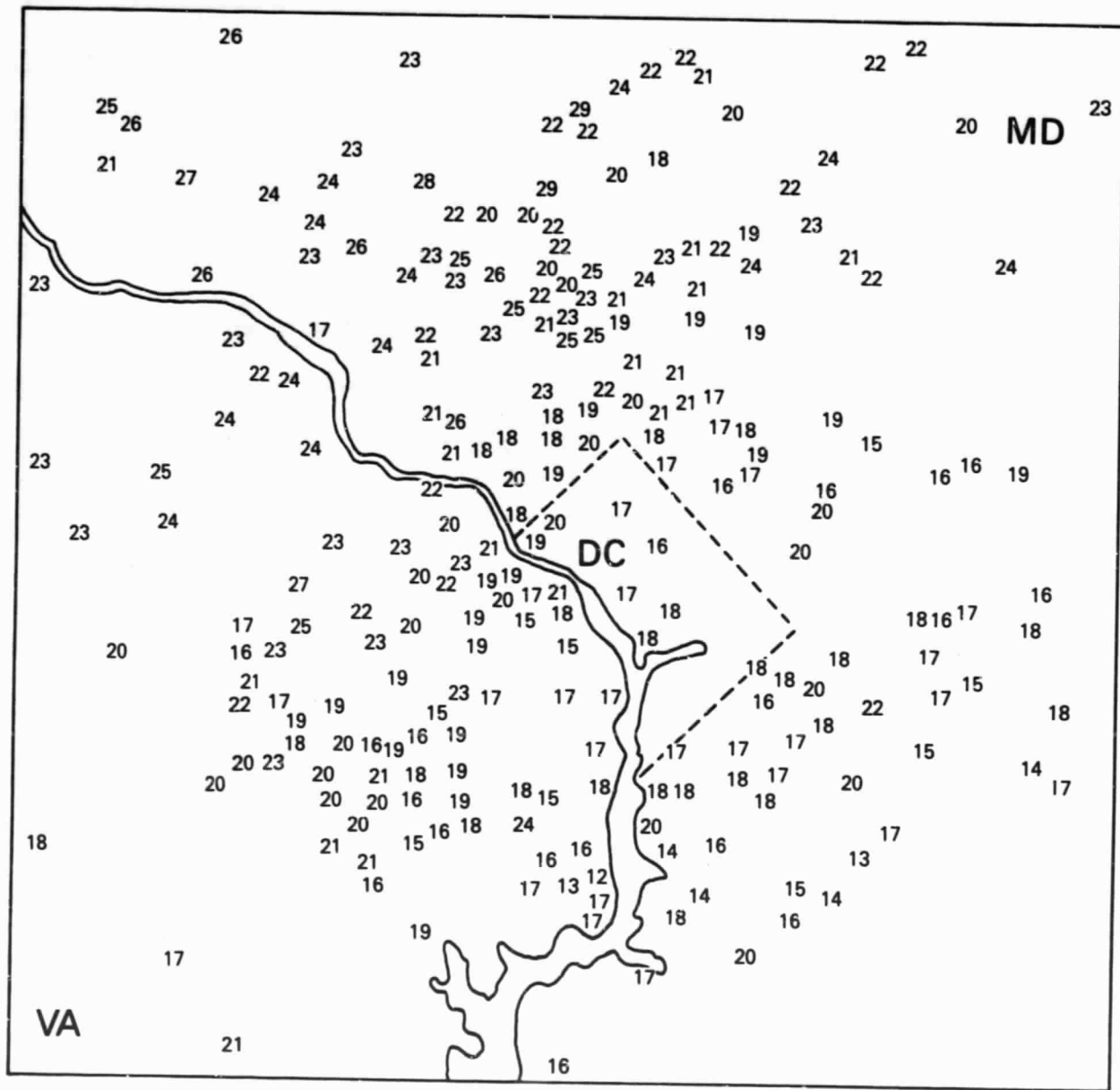
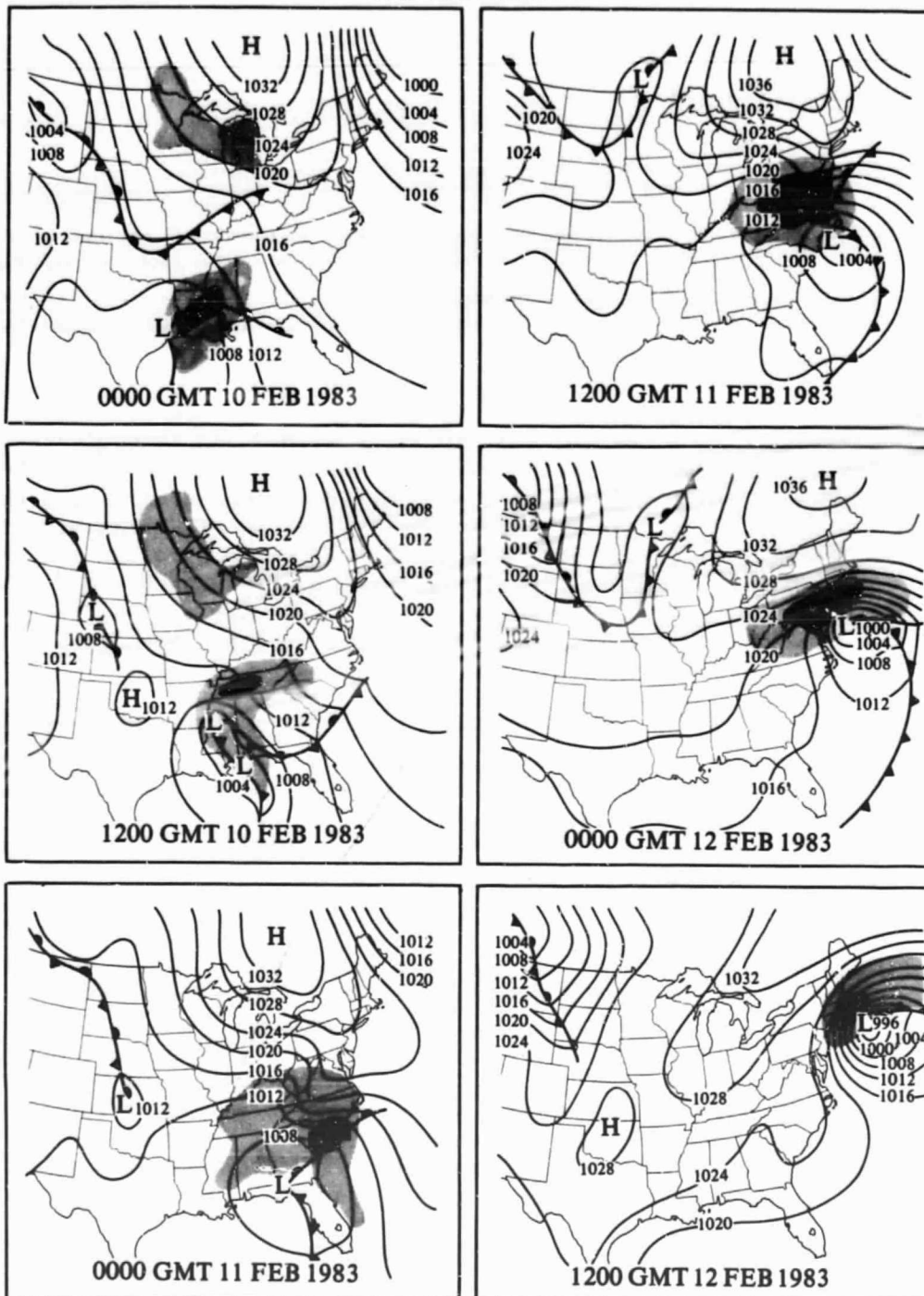


Fig. 75. Total snow accumulations for 10 to 12 February 1983 (in) for the Washington, D.C. metropolitan area. Snowfall measurements were taken from the Metropolitan Climate Review for February 1983.

Surface characteristics

- o Type "A" (Miller, 1946)
- o A 1040 mb anticyclone spread across the northeastern United States on 10-11 February as the cyclone was moving across the southeastern United States. The anticyclone was one of the few colder than normal air masses of the entire winter. Significant cold air damming occurred across the Middle and South Atlantic states on 10 and 11 February.
- o The surface low developed along the Gulf coast and then moved northeastward along the East Coast between 9 and 11 February. Its forward rate of speed varied between 10 and 20 m s^{-1} . The low moved northeastward up a pronounced coastal front along the Southeast coast, passing near Norfolk, Va. on 11 February. Heavy snow developed in the mountains of North Carolina and then in southern and western Virginia late on 10 February. The low then moved more to the east-northeast, out over the Atlantic Ocean, producing heavy snow to the west, north, and northeast of the center.
- o The cyclone deepened erratically as it propagated from Florida to southeastern Virginia on 10 and 11 February. Pressures never fell below 1015 mb in the major cities of the Northeast with erratic pressure tendencies during the course of the storm. Evidence presented by Bosart and Sanders (1985) indicates that gravity waves were an integral part of the evolution of this storm.
- o Thunderstorms were widespread from Washington, D.C. to New York City the afternoon and evening of 11 February with snowfall rates of 2 to 5 in h^{-1} (5 to 12 cm) reported.
- o The distance between low and high pressure centers on the East Coast decreased as the storm moved up the coast on 11 February. This acted to increase the pressure gradient north of the low center and to increase the easterly fetch from the Atlantic toward the region of maximum precipitation.
- o The cyclone deepened rapidly (-3 mb (3 h)^{-1} or greater) only after it was out over the Atlantic after 1200 GMT 12 February.

SURFACE



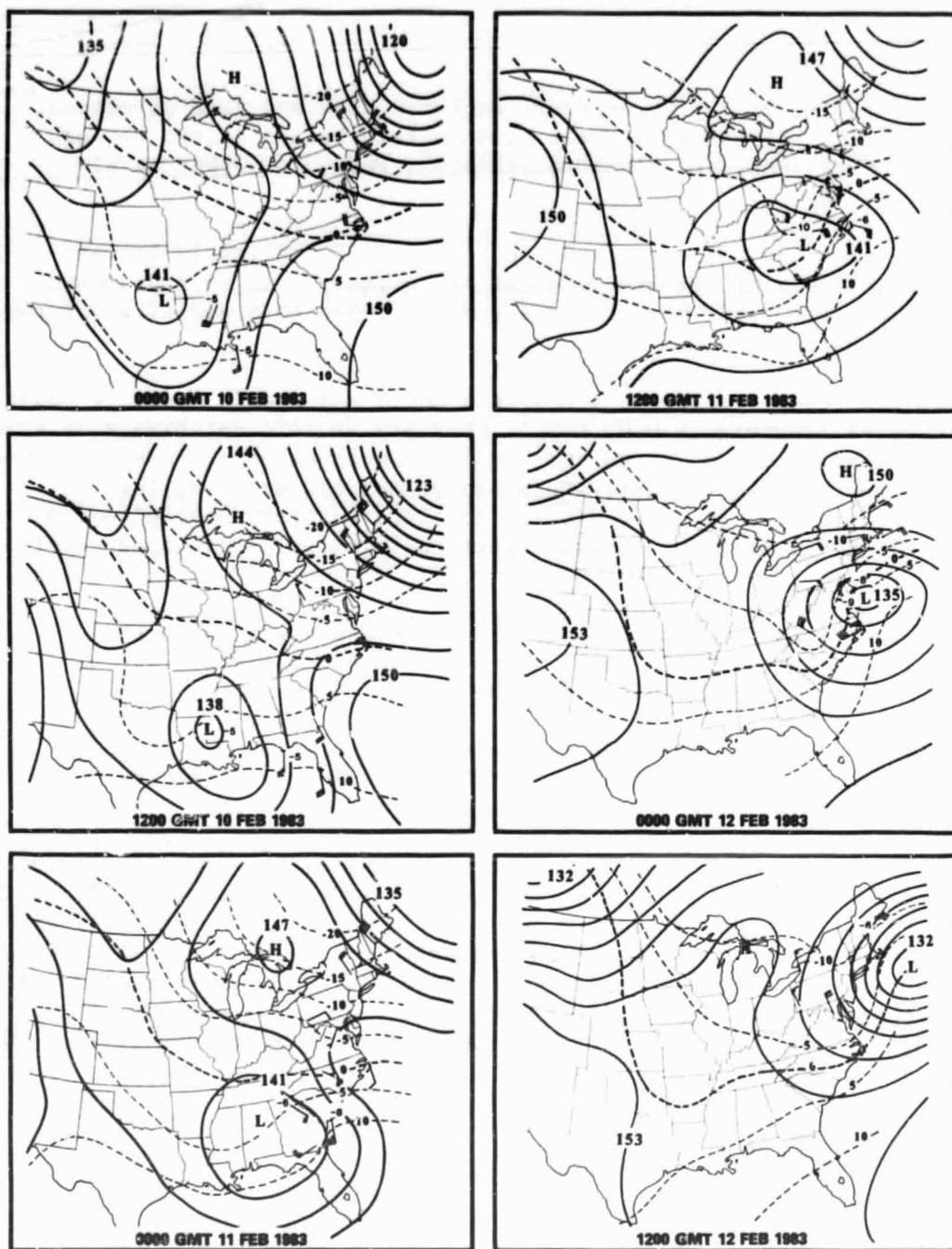
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Fig. 76. Surface frontal and weather analyses for 0000 GMT 10 February, 1200 GMT 10 February, 0000 GMT 11 February, 1200 GMT 11 February, 0000 GMT 12 February, and 1200 GMT 12 February 1983. See Fig. 2 caption for details.

850 mb characteristics

- o Prior to the storm, strong northwesterly flow and cold advection occurred at 850 mb across the northeastern United States through 0000 GMT 11 February, located beneath a region of upper-level confluence.
- o The 850 mb low alternately deepened and filled slightly between 0000 GMT 10 February and 1200 GMT 11 February. It then deepened slowly after 1200 GMT 11 February as it moved to a position off the East Coast.
- o The temperature gradient across the South and Middle Atlantic coasts increased sharply at 0000 GMT 11 February as cold northwesterly flow in the New England states and south to southeasterly winds increased near the Southeast Coast, where 850 mb heights were falling significantly. This occurred as moderate to heavy precipitation developed along the Southeast Coast near the well-developed coastal front.
- o The increase of temperature gradient was associated with the development of an "S"-shaped isotherm pattern between 1200 GMT 11 February and 0000 GMT 12 February.
- o The low center was located on the warm side of the 0°C isotherm through 0000 GMT 11 February, but became colocated with the 0°C isotherm as it reached the Atlantic Coast by 1200 GMT 11 February.
- o Although this case was associated with some of the deepest snowfall amounts of any of the cases, the low-level jets associated with this system were only of moderate intensity. East to northeasterly winds to the north of the 850 mb low center were observed only as high as 20 m s^{-1} (although several reports were missing). Nevertheless, the increasing southeasterly to easterly winds along the coast likely enhanced moisture transport into the region of heavy snowfall on 10 and 11 February.

850 MB



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Fig. 77. The 850 mb analyses for 0000 GMT 10 February, 1200 GMT 10 February, 0000 GMT 11 February, 1200 GMT 11 February, 0000 GMT 12 February, and 1200 GMT 12 February 1983. See Fig. 3 caption for details.

500 mb geopotential height characteristics

- o General features prior to cyclogenesis along the East Coast
 - A strong, nearly stationary ridge east of Greenland and a slow-moving trough across southeastern Canada dominated the circulation pattern that affected the northeastern United States. The trough in Canada and the general westerly flow across the northern United States produced a pronounced confluent zone over the Great Lakes region and northeastern United States on 10 and 11 February. A zonal flow pattern with several weak short wave troughs evolved into a ridge along the West Coast and two separate well-defined troughs east of the Rocky Mountains. One trough was associated with the East Coast storm while the other produced a new low center in the Gulf of Mexico by 12 February.
- o Characteristics of trough associated with East Coast cyclogenesis
 - The trough that produced the East Coast storm appears to be the merger of a short wave over the Gulf of Mexico and a weaker system moving east-southeastward across the Southern Plains on 10 February.
 - Between 0000 GMT 10 and 0000 GMT 11 February, the trough developed a negative tilt with marked diffluence immediately downwind of the trough axis over the southeastern United States. The surface low and heavy precipitation developed along the East Coast within the diffluent region of the negatively tilted trough, immediately upwind of the ridge axis between 0000 GMT 11 February and 0000 GMT 12 February.
 - The 500 mb trough deepened only slightly during the study period as the open wave trough formed a closed 5460 m center briefly at 0000 GMT 12 February as it reached the Middle Atlantic states.
 - The amplitude of the trough system increased slightly through 1200 GMT 11 February as the amplitude of the first Gulf of Mexico system increased at 1200 GMT 10 February and the amplitude of the merged systems increased by 0000 GMT 11 February. However, the amplitude of this trough system is relatively small when compared to some of the other cases.
 - The half-wavelength between the trough axis and downstream ridge appears to decrease as the ridge becomes better defined over the Middle Atlantic states by 0000 GMT 11 February.

Upper-level jet characteristics

- o Jet streak characteristics of the cyclone-associated trough and flanking ridges
 - Unlike some of the other cases, the jets propagating into the western, upstream portion of the trough that was associated with the East Coast storm remained rather weak as the several short waves merged into the negatively tilted trough at 0000 GMT 11 February.

- A jet streak near the base of the trough amplified over the southeastern United States after 1200 GMT 11 February as the cyclone was located in the diffluent exit region along the Atlantic coast. As shown in Part 1, the indirect circulation in the exit region of this jet is shown to directly influence the low-level warm advection and moisture transports toward the regions of heavy snow. The rising branches of transverse circulations in the exit region of the jet streak at the base of the trough in the Middle Atlantic states and in the confluent entrance region of the jet streak across New England at 1200 GMT 11 February combined to produce a sloped pattern of ascent corresponding to the region where heavy snow was falling.

o Other jet characteristics

- A 50 to 60 m s⁻¹ polar jet within the confluent flow over the northeastern United States from 0000 GMT 10 February to 0000 GMT 11 February coincided with the southeastward extension of the cold anticyclone over New England. In Part 1, the direct transverse circulation in the confluent entrance region of this jet is shown to contribute to the low-level cold advection pattern in the northeastern United States.
- An additional jet streak with noticeable cross-contour flow propagated and extended from the ridge crest in southwestern Canada toward the base of the second major trough over the southern United States by 1200 GMT 12 February and was associated with the development of a new cyclone over the Gulf of Mexico late on 12 February.

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500 MB HEIGHTS AND UPPER-LEVEL WINDS

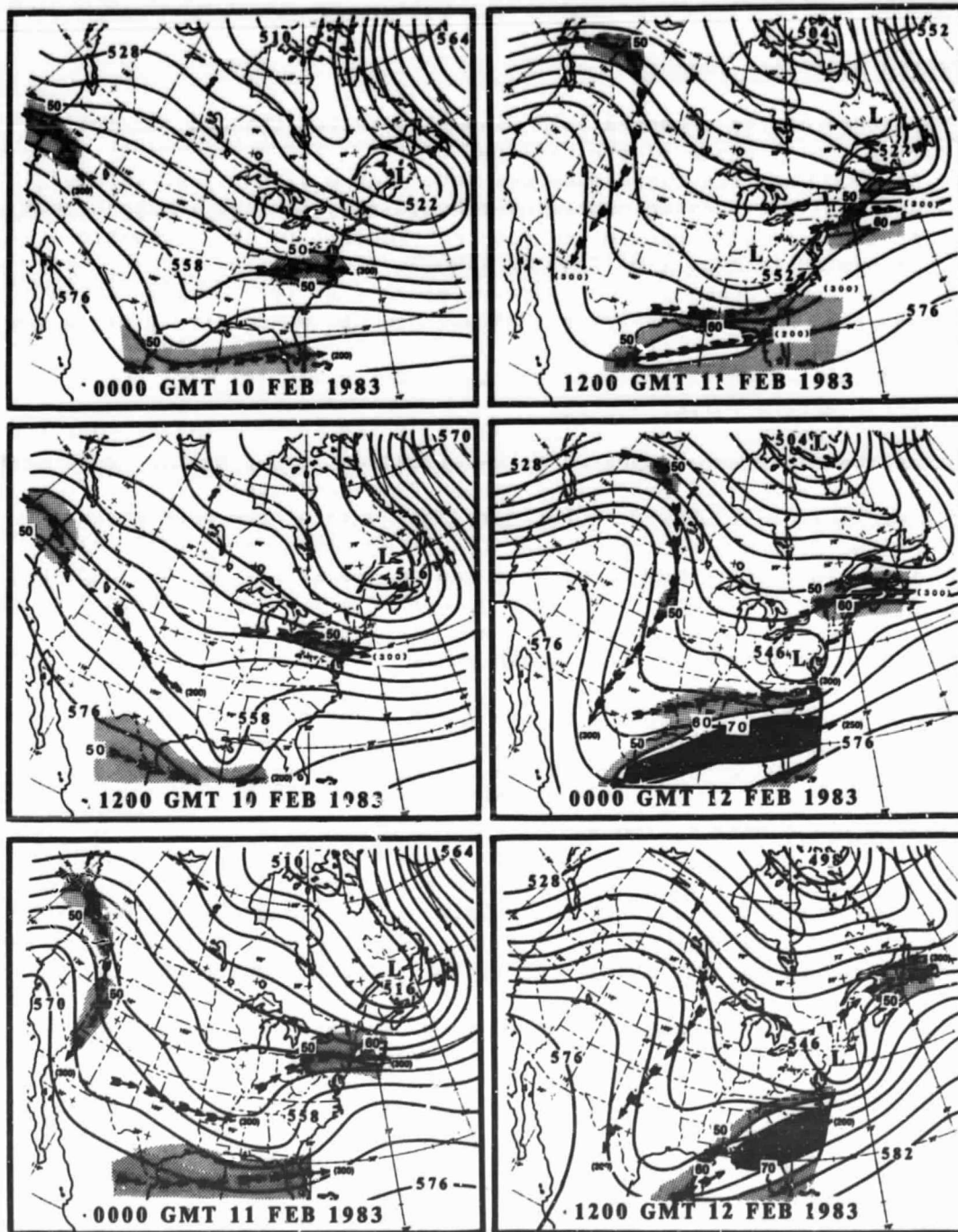


Fig. 78. The 500 mb geopotential height analyses and isotachs of maximum wind speeds for 0000 GMT 10 February, 1200 GMT 10 February, 0000 GMT 11 February, 1200 GMT 11 February, 0000 GMT 12 February, and 1200 GMT 12 February 1983. See Fig. 4 caption for details.

Infrared satellite imagery

- o The shape of the enhanced cold cloud top region changed character during the lifetime of the cyclone.
 - At 0000 GMT, the cloud mass was noted for a distinct western edge and small, organized center over Louisiana, similar in appearance to the initial stages of cyclone development in the schematic presented in Fig. 1 of Carlson (1980).
 - A distinct "comma-shaped" pattern emerged at 1200 GMT 10 February and 2330 GMT 10 February as the surface low moved slowly along the Gulf Coast. The northern edge of the cloud shield aligned generally with the axis of the confluent polar jet over the northeastern United States.
 - The comma-shaped pattern changed character by 1300 GMT 11 February as the cloud mass appeared to be stretched into a narrow, east-west aligned region of cold cloud tops. This band moved slowly northward by 2300 GMT 11 February into much of the northeastern United States and drifted east to off New England by 1230 GMT 12 February as heavy snows were ending across eastern New England. Again, the heaviest snows were occurring along the southern edge of the high cloud tops associated with this band in the diffluent region downstream of the trough axis.
- o The very cold cloud tops over New Jersey, southeastern New York, and New England at 2300 GMT 11 February reflect the imbedded convection that produced very heavy snowfall and may also represent the gravity waves that appear to influence the snowfall rates for this case (Sanders and Bosart, 1984).
- o The position of the surface cold front and low center corresponded well with the back edge of the "white" scale cloud edge at 0000 GMT and 1200 GMT 10 February. At later times, the surface low center was displaced south and west of the region of high cloud tops.
- o A broad clear area was located near the surface low center over the Atlantic at 1200 GMT 12 February (see Fig. 11 in Part 1).

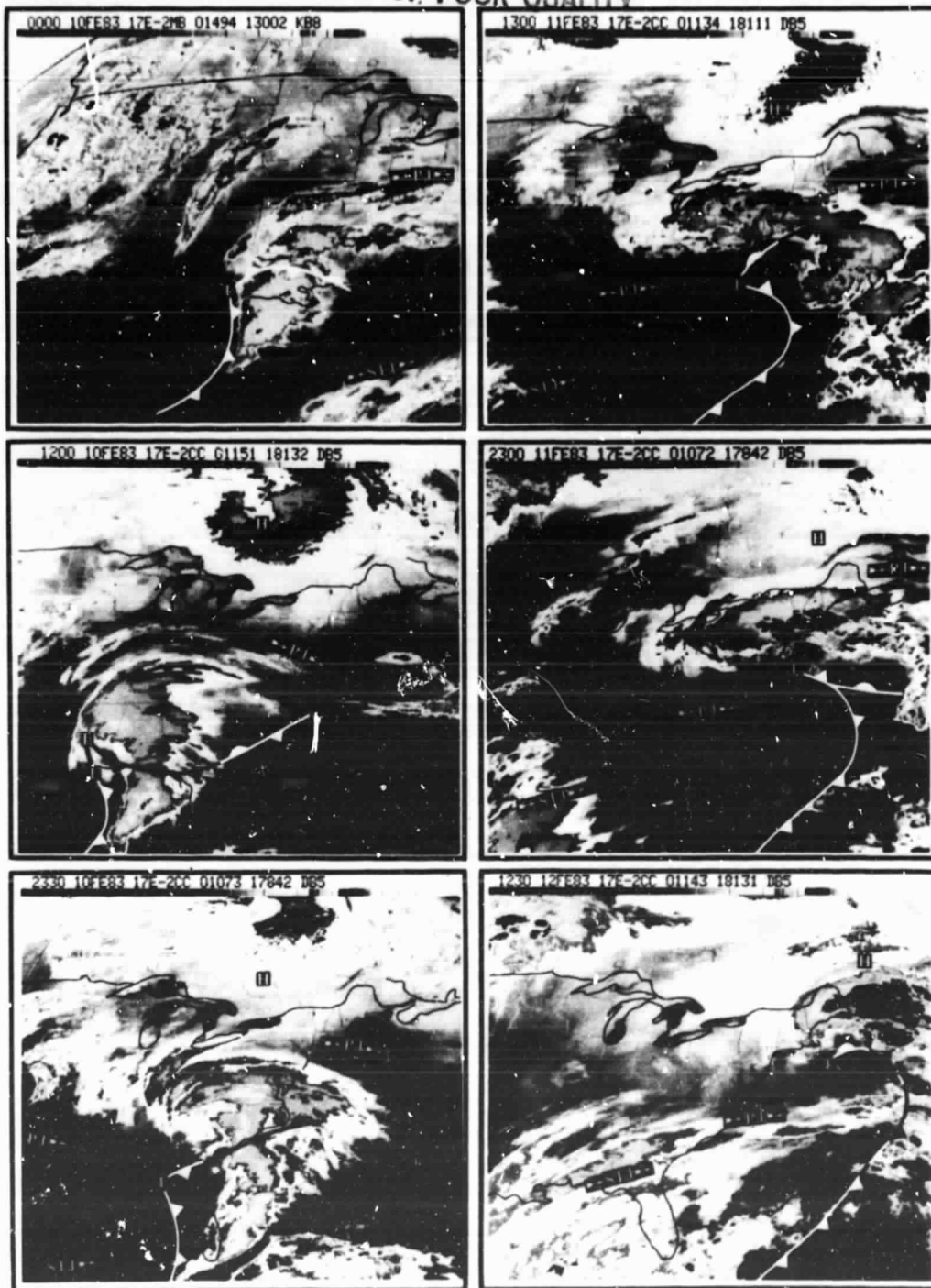


Fig. 79. GOES-East infrared satellite images for 0000 GMT 10 February, 1200 GMT 10 February, 2330 GMT 10 February, 1300 GMT 11 February, 2300 GMT 11 February, and 1230 GMT 12 February 1983.

3. Discussion

Eighteen cases of major East Coast winter storms dating from 1960 to 1983 are examined to gain a perspective on how these weather systems organize and evolve prior to and during cyclogenesis along the Atlantic Coast of the United States. A multi-level overview of each storm is presented utilizing snowfall charts, surface, 850 mb and 500 mb analyses, upper-level jet analyses, and available satellite images. The general characteristics of these storms derived from the charts just cited are summarized in Part I.

The discussion of the surface analyses emphasize two "types" of cyclones defined by Miller (1946), their tracks, propagation rates, and deepening characteristics and often observed coastal frontogenesis. The position and intensity of cold surface anticyclones and associated "damming" of cold air to the lee of the Appalachian Mountains are also examined.

The 850 mb analyses and discussions emphasize the presence of northwesterly flow and cold air advection prior to East Coast sea-level cyclogenesis. The 850 mb deepening rates are contrasted with surface deepening rates, as well as whether dual centers associated with secondary sea-level development are also observed at 850 mb. Characteristics of the lower-tropospheric temperature gradient, the development of an "S"-shaped temperature pattern, and the location of the 0°C isotherm with respect to the 850 mb low are also examined at this level. Finally, the formation of low-level jet streaks are related to 850 mb low intensification and precipitation patterns. The combination of the "S"-shaped thermal patterns

and strong low-level winds near the coast is related to enhanced warm air advection and moisture transports, especially during periods of rapid cyclogenesis.

The 500 mb geopotential height analyses provide an overview of the middle-tropospheric circulation across North America preceding and accompanying the development of each storm, including a description of the presence of confluence across the northeastern United States and southeastern Canada prior to East Coast cyclogenesis. Jet streaks within this confluent upper-level height field are also noted. The discussion also provides descriptions of various aspects of the troughs associated with the cyclones, including the development of a closed center at 500 mb, diffluence, a negatively tilted trough axis, an increase of geopotential gradients at the base of the trough, changes in amplitude and half-wavelength between the trough axis and downstream ridge. Also present is an examination of upper-level jet streaks, which concentrates on the areal and temporal changes of wind maxima, especially at the base of the trough and within the downstream ridge. The evolution of the jet/trough systems varies from case to case, but appears to act to increase divergence aloft (and associated positive vorticity advection) immediately prior to and during rapid surface development. The jet/trough systems provide the upper-level divergence/baroclinic instability needed to initiate the development of a cyclone, but topographical features related to the East Coast (in particular, land-sea effects, the Appalachian Mountains, and boundary layer processes over the ocean) act to focus or modulate the rapid development phase of the surface cyclone.

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BIBLIOGRAPHIC DATA SHEET

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16. Abstract Snowfall, surface and upper air charts, and available satellite images are presented for eighteen major East Coast snowstorms that occurred between 1960 and 1983. The charts and descriptions of key fields are provided so that students, weather forecasters, and researchers alike can visualize how a large sample of major winter cyclones form and intensify. Although there are noted similarities in certain aspects of the surface and upper-tropospheric development of the storms, significant case-to-case variability precludes the ability to effectively composite these weather systems.			
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